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16. ABSTRACT

A methodology is developed to use space-time analysis and ecosystem modeling to assess the secondary impacts of wastewater treatment facilities (i.e., urbanization) on the ecosystem. The existing state of the ecosystem is described with emphasis on the dynamic, periodic, trend, and gradient processes. Ecosystem models are used to project consequences of project alternatives. Incremental and synergistic effects are indicated along with suggested operational adjustments to minimize ecosystem impacts from the recommended project.

Ecosystem models are described and the literature on impacts is reviewed. A case study of urbanization at Lake George, NY, emphasizes the usefulness of the components of ecosystem models by linking units from several studies with a new model (LAND). This new model is described and documented. A case study of a new town (Woodlands, TX) indicates the changes in current methodologies which are required to adopt space-time analysis and ecosystem modeling to the assessment of the effects of urbanization on the ecosystem.

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ECOSYSTEM IMPACTS OF URBANIZATION ASSESSMENT METHODOLOGY

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ABSTRACT

This report provides a review of existing ecosystem models and the impacts or urbanization on natural ecosystems. It has long been recognized that infrastructure development such as highways and wastewater treatment facilities affects urbanization. The placement of trunk sewers and highways affects the pattern of development and the capacity of these systems affects the rate of development in urban areas. EPA, therefore, asked the Institute of Ecology to review the International Biological Program (IBP) biome models to determine their usefulness in predicting ecological effects associated with urbanization and, to the extent possible, to develop simplified models to make such predictions. Access to IBP information has been freely provided by various IBP offices although some of the information has not been placed in completed reports and many of the models are in active stages of development. The summaries of the modeling efforts result from the study of internal documents, conversations with a number of the ecosystem modelers, the assistance of workshop participants, and the contributions of volunteers. Most of the documents referred to may be obtained from the International Biological Program, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 37830.

The results of the work showed that at this point in time there was no model, no matter how sophisticated, that could be used to predict the ecosystem effects of urbanization. There are, however, models which are useful in predicting specific effects from specific perturbations. To this end, a logical sequence (space-time analysis) of exploring the potential ecological effects associated with various aspects of urbanization was developed.

We are most appreciative of all assistance received. The IBP studies have been the efforts of interdisciplinary teams, and all participants, contributors, and authors referred to in the literature cited deserve special thanks.

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INTRODUCTION

David L. Jameson

During the past three decades, the U.S. has experienced an increasing trend towards urbanization that has been at the same time both systematic and uneven. Outlying portions of urban areas have been growing while the population numbers in the central areas of cities have been leveling off and in some cases actually declined. This growth pattern is consequent to the movement of people and jobs to suburbia and exurbia. The result has been the evolution of urban communities from small towns into cities, metropolitan areas, and now urban regions. This immense growth has brought forth a vast array of goods and services, an ever expanding spatial distribution of people, as well as a host of urban problems. Because of the complexity and urgency of urban problems, the urban ecosystem approach has been developed to provide a comprehensive and interdisciplinary model to aid us in studying the complicated nature of our cities (Stearns and Montag, 1975).

The inexorable trend toward very large, extremely complex urban places is a result of forces whose origins lie in the political, economic, and social systems of our society. Of particular significance for this study, two forces emerge as important factors in promoting or sustaining urban growth: a) population growth, and b) the expansion of public investments such as highways and wastewater treatment facilities. An essential coupling between urban highways and urban-suburban growth patterns has long been recognized. The linkage between them can be assessed from two, quite opposite, theoretical positions. One theory asserts that new or improved highways are a response to expressed demand. The alternative theory suggests that the linkage is developmental in that new transport facilities generate certain patterns of urban growth and development.

The position taken here is that both development and demand processes are taking place, and the expanded construction of highways and wastewater treatment facilities will be associated with the accommodation or promotion of urban regional growth. This growth is significant in that the activities consequent to it impact upon the natural ecosystem.

Clearly the ultimate source of ecosystem impacts is growth in the numbers of people and growth in the amount of resources required by each person. Impacts on the ecosystem result from changing use of land as it is converted from natural areas to agriculture and/or suburban, commercial, industrial uses, from the migration toward, from, and between urban centers, and from the movement of people from the urbanized areas into the surrounding countryside for recreational activity. Indirect impacts result from the promotion of growth, development, and urbanization which result from some population already being present.

Areas may be overpopulated with respect to resource distribution and may be overpopulated with respect to the amount of resources. When population growth is stimulated at rates greater than assured resource availability, a number of environmental impacts become apparent and many of these impacts are on the ecosystem. Open areas become trash dumps and streams; rivers and lakes absorb pollution at levels far higher than in areas where social amenities are maintained. While it is not always easy to determine the exact amount of impact on the ecosystem that will occur because of the lack of available resources for the number of people, it is clear that, when population growth is stimulated by wastewater treatment facilities or by highways, both social and ecosystem impacts will occur.

The significance of secondary impacts has been stated explicitly by Robert H. Twiss. "Environmental impacts are seldom important solely in terms of their direct physical effects.

That is, if a road is built into a new area, the soil erosion and visual scars are important, but not as important as the 'bomb-baret' effect at the end of the road that generates new housing, followed eventually by the need for many other services. Most of the people involved recognize that the question is not whether we should treat secondary effects, but rather, given that secondary effects are the most important of the two, how we compute and weigh them."

The National Environmental Policy Act of 1969 in Section 102 (c) requires all agencies of the Federal government to:

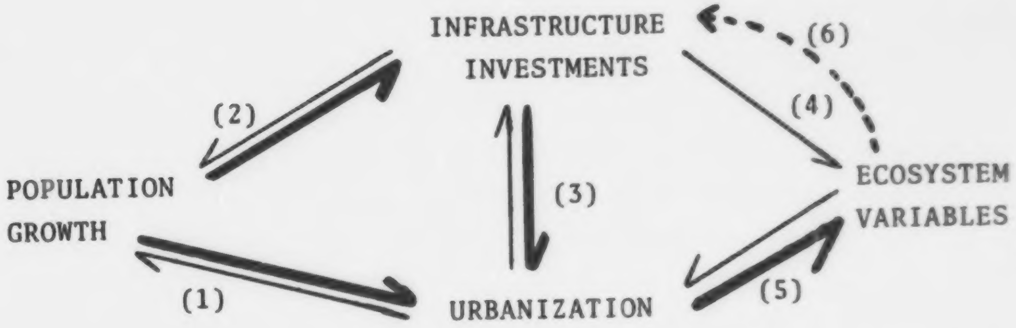
> "(C) Include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on -
>
> (i) The environmental impact of the proposed action,
>
> (ii) Any adverse environmental effects which cannot be avoided should the proposal be implemented,
>
> (iii) Alternatives to the proposed action,
>
> (iv) The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
>
> (v) Any irreversible and irretrievable commitments of resources which would be involved in the proposed action, should it be implemented."

Additionally, the Council on Environmental Quality published guidelines (38 Fed. Reg 20550-20562, August 1, 1973) which indicate in Section 1500.8 (a) (3) "(ii): Secondary or indirect, as well as primary or direct, consequences for the environment should be included in the analysis". Further, Preparation of Environmental Impact Statements includes a definition of secondary impacts (40 CFR Part 6, 40FR16814 (April 14, 1975) in Section 6.304 (2) and (3).

> "(2) Primary impacts are those that can be attributed directly to the proposed action. If the action is a field experiment, materials introduced into the environment which might damage certain plant communities or wildlife species would be a primary

> impact. If the action involves construction of a facility, such as a sewage treatment works, an office building or a laboratory, the primary impacts of the action would include the environmental impacts related to construction and operation of the facility and land use changes at the facility site.
>
> (3) Secondary impacts are indirect or induced changes. If the action involves construction of a facility, the secondary impacts would include the environmental impacts related to:
>
> (i) induced changes in the pattern of land use, population density and related effects on air and water quality or other natural resources;
>
> (ii) increased growth at a faster rate than planned for or above the total level planned by the existing community."

With mounting concern over the secondary effects on natural and agricultural environments, particularly from urbanization, it has become apparent that an objective, analytical strategy is necessary to assess the subtle, but far-reaching, impacts of wastewater treatment facilities (WTF) and highways. Because such a strategy could profit from recent interdisciplinary modeling experience and findings in ecosystem science, The Institute of Ecology (TIE) was given the charge of developing a generalized methodology. Specific attention was to be given to one of the biome types modeled by the U.S. International Biological Program (IBP). To assess these impacts, we have relied on an urban ecosystem approach and, though this schematic is highly simplified, it has served an heuristic function.



(E)

Figure 1-1. Interaction of urbanization processes.

The fundamental component of the approach is the process of urbanization. The approach also focuses on the reciprocal nature of factors that affect urbanization (1) (2) (3), as well as the impact urbanization has upon the ecosystem (4) (5).

(1) Population growth enhances urbanization, and, at the same time, urbanization may influence population growth.

(2) Population growth places demands upon society for roads and wastewater treatment facilities (i.e., public investments), and, at the same time, the provision of the facility expands the capacity of society to accomodate high levels of population.

(3) The continuing process of urbanization via population growth and socioeconomic pressures creates a demand for facilities, while the facility enables the urban region to accomodate more people.

(4) The facilities have a primary (direct and indirect) impact upon the natural ecosystem.

(5) Urbanization induced by population growth and expanded facilities impacts the natural ecosystem. These secondary impacts are the focus of this study.

(6) A missing link to be provided by this study by means of operational changes.

Continued population growth is dependent on the availability of resources, the most important of which, for human health, includes man's dependency on larger (spatially speaking) ecosystems for food, fiber, energy, and housing. Reductions in man's ability to manage a portion of the ecosystem for the production of essential biological commodities will serve to inhibit the rate of growth of human welfare; that is, a feedback does exist between man and the availability of his resources. Modern technology has relieved man of much of his dependency on natural sources for the comforts of the physical environment such as temperature and water. However, modern technology cannot decrease man's dependency on the ecosystem but it can, and indeed it has, decreased the influence of the feedback in depressing population growth, public facility investments, and urbanization. Periodically the balance between available resources and the consuming population will be restored, even in the case of modern man, especially if systems requiring sophisticated management break down for whatever reason.

Planners, engineers, and other components of the decision making process have developed techniques, models, methodologies, flow charts, and programs to achieve their results. The major development of ecosystem models has been the result of work supported through the studies of the International Biological Program although many others are useful. This report attempts to prepare and document a methodology which integrates the models of the ecologist into the decision-making process.

The following report provides a review of various ecological modeling efforts which can provide a nucleus for additional effort. Some of the literature describing impacts on ecosystems is reviewed and an expansion of the proposed methodology is detailed. Several case studies are presented separately to suggest ways the methodology and the report may be used.

Demonstration of the linkage between urbanization and ecosystem variables requires interaction between engineers, planners, ecologists and others and like any multidisciplinary project, reaching the objective is a "very hard thing to do."

THE INSTITUTE OF ECOLOGY

At the time this contract was initiated (summer, 1974), the Environmental Protection Agency (EPA), the Council on Environmental Quality (CEQ), and the Department of Housing and Urban Development (HUD) had ongoing research studying the cost of sprawl and the secondary effects of highways and wastewater treatment and collection facilities. These studies explored the impacts of highways or wastewater treatment and collection facilities on patterns of urbanization, and how various urbanization patterns affect human activities, such as commuting time. However, the consequences of these actions on the natural ecosystems, of which man is a part, had not been explored.

For this undertaking, the EPA turned to The Institute of Ecology (TIE) to obtain this analysis of the secondary impacts of urbanization on agricultural and non-urban ecosystems. TIE is a federation of more than 100 western hemisphere institutions engaged in ecological research. TIE serves as the initiator and coordinator of multi-disciplinary and multi-institutional projects that are too large and complex for one researcher or one research organization.

SPECIFIC OBJECTIVES

Presently, the EPA, among its many functions, reviews Environmental Impact Statements (EIS's) on highways and prepares EIS's on wastewater treatment facilities. The EPA, recognizing the variety of quality and content of the EIS's provided to them for review and the difficulty of performing adequate review, has asked TIE to help to 1) determine which natural processes appear most susceptible to impacts of a) increased urbanization in general and b) secondary effects of public infrastructure investments, specifically highways and wastewater collection and treatment facilities; and 2) develop a generalized methodology describing effects of publicly supported actions (i.e., infrastructure investments) upon natural ecosystems. Specifically, the tasks to be performed were as follows:

(1) Impact Identification - In one of the biome types (specifically the eastern deciduous forest), TIE shall determine which natural processes appear to be most susceptible to the impacts of
    a) increased urbanization in general
    b) secondary effects of public infrastructure investments (e.g., wastewater treatment facilities, highways).

(2) Quantify Characteristics - Document and identify characteristics capable of ready monitoring from studies that have undertaken to quantify or qualitatively describe changes identified in Task (1).

(3) Hypothesis and Methodology Formation - Develop a generalized methodology to describe effects of Task (1).

(4) Documenting the Methodology - Prepare a final report setting forth finding of Tasks (1) and (2) and fully document the proposed methodology.

(5) Testing the Methodology - Undertake one or more case studies to validate and amplify the methodology.

THE INTERNATIONAL BIOLOGICAL PROGRAM (IBP)

In 1959, biologists [members of the International Union of Biological Sciences (IUBS) and the International Council of Scientific Unions (ICSU)], recognizing the need for cooperative international study of the world wide problems of resource management and human adaptability to environmental change, proposed an international program of biological studies concerned with productivity, man, and the environment which might yield a worldwide consensus on goals for the benefit of humanity as well as produce some solutions to environmental problems. A Special Committee for the International Biological Program (IBP) authorized by the ICSU in 1964 has directed this program. The first U.S. program became operational in 1967 and was endorsed by Congress in 1970.

The goals of USIBP concerned furthering scientific training and research in resources management and developing international exchanges of the results. The scientific objective was to improve understanding of ecosystems by:

formulating a basis for understanding the interaction of components of representative biological systems;

exploiting this understanding to increase biological productivity;

providing the basis for predicting consequences of environmental stress, both natural and manmade;

enhancing man's ability to manage natural resources;

advancing knowledge of man's genetic, physiological and behavioral adaptation. (U.S. participation in IBP, 1974).

The USIBP program was divided into two components: environmental management (studies of productivity and natural resources) and human adaptability (studies of man's adaptability to changing environments). The former component is of greatest interest to this study. Its major accomplishments grew out of the analysis of ecosystems. These analyses initially developed as integrated research programs in five biomes (grasslands, eastern deciduous forest, desert, coniferous forest, and tundra). The purpose of the studies was to advance understanding of ecosystems by measuring and modeling the rates of change in system components, to expand the data base on whole systems, to increase the reliability of production estimates and to improve the scientific basis of resource management.

In addition to the five biome studies, the ecosystem analysis program focused on the origin and structure of ecosystems and the biological productivity of upwelling ecosystems. Other studies included marine mammals, aerobiology, biological control of insect pests, conservation of plant genetic material, and conservation of ecosystems.

In order to develop a system of equations capable of describing ecosystems, IBP workers have concentrated on physical and biological processes: H_2O and mineral transport, photosynthesis, respiration, grazing, production, decomposition, and mineralization. Several years were spent on processes, including the formulation of mathematical models for later analysis of entire ecosystems.

The biome studies have contributed to an understanding both of the manner in which basic biological, physical, and chemical processes regulate ecosystems and of the structural or internal regulatory mechanisms within the system as a whole. Comparison of stored carbon pools and their rates of transformation illustrate the properties of a variety of ecosystems. These and other studies may be useful in evaluating potential hazards to ecosystems on the basis of minimal field measurements and a knowledge of system properties rather than on the basis of massive field studies.

Most of the progress made by USIBP concerned developing systems models and an understanding of ecosystems productivity and the physical and chemical parameters of ecosystems and their related processes. Such studies concentrate on the means by which structural characteristics and systems properties govern functional characteristics such as the flow of energy, cycling of materials, and responses to perturbations. Complex mathematical modeling of these characteristics are a necessary part of understanding the dynamic behavior of systems. Recent advances in systems sciences were used by IBP workers to great advantage.

A small workshop held in the summer of 1974 defined problems and identified research staff and ecologists. A staff meeting in the winter of 1974 resulted in a preliminary methodology. A revised methodology and a working paper were prepared and 200 copies distributed to ecologists in the 100 institutions that participate in The Institute of Ecology. Another workshop was held in the late summer of 1975. The final document includes the suggestions of the workshop participants, and those contributed through the mail, and those resulting from the formal T.I.E. review process.

METHODOLOGY
[EXECUTIVE SUMMARY]

No widely applicable general methodology for preparing or reviewing Environmental Impact Statements now exists and those which have been developed are only approximations of the ideal. However, methodologies for impact assessment share certain common characteristics. To analyze an impact, they describe the project or program which represents the source of changes and the system or environment which will be perturbed or modified. While measurements of causes and effects can make the analysis more quantitative and clear, statements of assumptions can make it more open and objective. The analysis is usually qualitative and of necessity has many subjective elements that result from conscious or unconscious value judgements which affect the selection or weighting of factors to be considered.

Methodologies now available fall into broad categories: maps, matrices, networks or graphs, and models (Warner and Preston, 1974). Dorney (1973) suggests that the use of a team of experts or specialists may provide the best, quick, cheap and direct analysis of single effects. An appropriately selected team would provide the latest information and group dynamics would provide the necessary systems analysis. Some methodologies, of course, use elements from two or more categories; while these hybrids have not been common in published methodologies, they are the usual approaches used in the preparation of EIS.

Warner and Preston (1974, p. 1) claim "There is no single 'best' methodology for environmental impact assessment." Additionally, the seven criteria for evaluation which they suggest provide no clear choice of methods for the analysis of the secondary effects of urbanization in the Eastern Deciduous Forest Biome. Armstrong (1972) thinks that an approach can be developed which uses the best components of each of the available methods and calls this "Space Time Analysis." Frug _et_ _al_. (1974) and Rowe _et_ _al_. (1974) appear to have had some success in impact assessment using an approach which combines the resources of several methods. We have relied on this approach.

A generally applied "systems approach" to urban ecosystems combining maps, matrices, networks, and models in a Space-Time Analysis provides the informational content needed by the non-scientist decision-makers while assuring the precision and confidence intervals desired by the professionals. Additionally, this approach allows new techniques, new models, and new ideas to be added to the system without discarding previous work or requiring a complete overhaul. In short, the methodology is able to evolve.

The information obtained by projecting changes in ecosystems is significant for Environmental Impact Statement writing and review. The quality of our environment relies on the EIS process as an informational feedback loop before the project is undertaken. The existing economic and political institutions are not designed to collect or process this class of information. Consequently, the EIS procedure provides the requisite information by institutionalizing a negative feedback loop to anticipate and assess impacts. This methodology is an attempt to expand the information to be assessed--information that may provide a better guide for the full consideration of the dynamic environmental and ecological processes when highway and wastewater treatment facilities are proposed.

SPACE-TIME ANALYSIS

Purpose. - The purpose of the methodology is to provide an analysis of the direct impact of urbanization (i.e., the indirect or secondary impacts of public investments, e.g., Waste Treatment Facilities and Highways) on ecosystems and agricultural systems. Consulting specialists are assumed to have the requisite knowledge and experience with the local situation to identify the appropriate techniques.

The proposed Space-Time Analysis requires several general steps.

I. Description of the existing state including
   a. identification and location of ecological units and categories
   b. identification and characterization of the dynamic ecological processes
   c. description of the historical stages and setting
   d. identification of environmental goals.
   e. projection and description of changes which will occur without additional human intervention (no action)

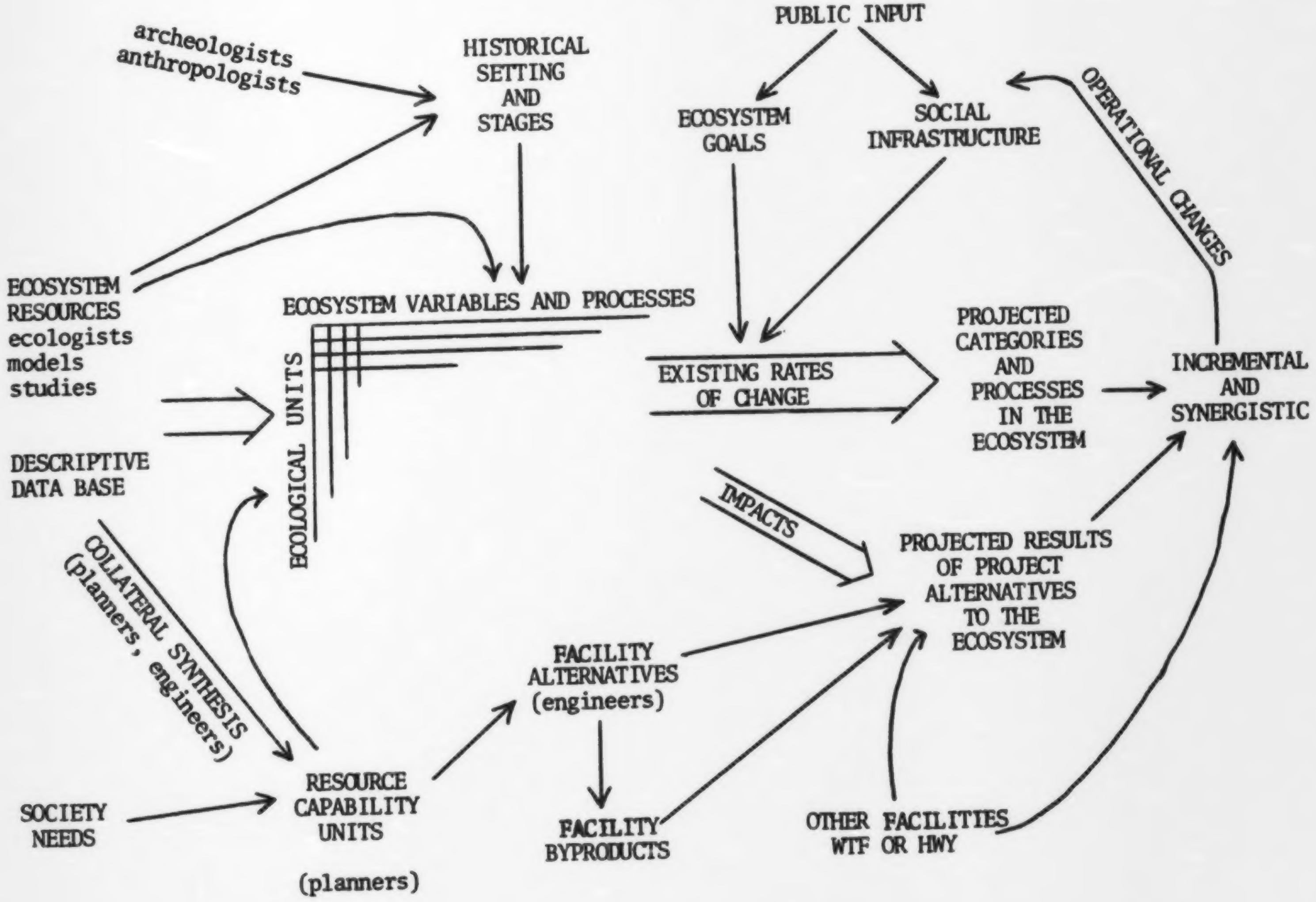
II. Description of each project alternative and its consequences

III. Description of incremental and synergistic effects accompanying each project alternative

IV. Recommendation of a specific action

V. Statement of required operational adjustments which result from the recommended project.

FIGURE 1-2. SPACE TIME ANALYSIS


archeologists
anthropologists
HISTORICAL SETTING AND STAGES
PUBLIC INPUT
ECOSYSTEM GOALS
SOCIAL INFRASTRUCTURE
OPERATIONAL CHANGES
ECOSYSTEM RESOURCES
ecologists
models
studies
ECOSYSTEM VARIABLES AND PROCESSES
ECOLOGICAL UNITS
EXISTING RATES OF CHANGE
PROJECTED CATEGORIES AND PROCESSES IN THE ECOSYSTEM
INCREMENTAL AND SYNERGISTIC
DESCRIPTIVE DATA BASE
IMPACTS
PROJECTED RESULTS OF PROJECT ALTERNATIVES TO THE ECOSYSTEM
COLLATERAL SYNTHESIS
(planners, engineers)
FACILITY ALTERNATIVES
(engineers)
SOCIETY NEEDS
RESOURCE CAPABILITY UNITS
(planners)
FACILITY BYPRODUCTS
OTHER FACILITIES WTF OR HWY

DESCRIPTION OF THE EXISTING STATE

The existing regionally specific data base constitutes the basis for identification of ecological units. While regional computerized data banks are not yet common, their expanding use for planning suggests that they will likely be available in areas subject to rapid urbanization. Aerial photographs, satellite imagery, topographic maps, soil studies, regional planning documents, zoning ordinances, surface and soil hydrology, drainage patterns, water quality, air, water, and solid waste pollution sources, vegetation types, highway access, recreation access, climate and existing land use and economic characteristics provide useful values which are frequently available in banks or in the public sector (library shelf, government records).

Planners, engineers, developers and others use a variety of techniques to organize and classify resource and human use data to determine the resource capability of a given site; maps, matrices, cluster analysis, gradient analysis, ordination techniques, and discriminant analysis may afford useful synthesis. These studies are typically economically oriented with human use criteria emphasized to provide the basis for the identification of resource capability units. One or two ecologists might participate in a team effort for the determination of resource capability units. Ecologists would use a subset of the same data with emphasis on resource criteria, take into account local site specific factors, and use the same techniques to identify the presence and distribution of significant ecological units. A team of ecologists will be required to identify significant ecological units because the selection is dependent on the identification of ecological variables and processes some of which may be highly site-specific.

Use of all the available variables in every impact analysis will be inappropriate. Some are extremely difficult to estimate or to interpret, and working ecosystem models using some are not universally available. However, the two workshops identified some ecosystem characteristics which should be discussed in every analysis of the secondary impacts of a Wastewater Treatment Facility or Highway; these are:

I. Microclimate: including changes in temperature, precipitation, and wind velocity

II. Soil: including changes in moisture type and erodibility

III. Hydrology: including changes in surface and subsurface waters using hydrographs of discharge vs. time and estimates of quantity and direction of ground water flow

IV. Species composition: including changes in distribution and abundance, and demographic characteristics of species (age of stands, seasonal phenology)

V. Food chains: including nutrients and changes in structure and relations with emphasis on decomposers

VI Succession: changes in the seasonal, gradient, and trend characteristics of ecosystem, agricultural, and urbanized situations

VII. Interrelations between terrestrial and aquatic: including changes in material and energy flow and species involved.

Any locality has an existing set of ecological units, many of which can be identified by terms familiar to the decision-maker. The categorization and presentation of these ecological units should emphasize ecosystem types (in addition to human activity), and presentation of the units and projected changes can be by sequential maps or by maps with overlays. One available method is described by Dansereau (1974). The analysis should highlight those seasonal, successional, and long term trend characteristics which are most subject (sensitive) to change.

The probable course of urban development both with and without the project can be detailed by planners and engineers. The time of that development and the area impacted constitute important inputs to the ecological analysis; thus both time and space boundaries and relations are significant. For each ecological unit, potential changes should be considered in light of specifically indicated time and space boundaries to identify how significant their effects would be compared to the effects which would result as consequences of the proposed human intervention.

The team of ecologists should:

1. Develop a comprehensive checklist of the potentially available and needed information to determine the ecological units and the ecosystem structure and functions. Ecological goals, environmental preserves, parks, endangered species, and the historical stages and setting should be indicated by sociological, paleontological, and archaelogical studies. The list should be regional- and site-specific.
2. Identify the natural forces producing change including succession and seasons (trends and cycles) in the variables: 1) ecosystem variables and processes, 2) existing sources of human interventions, 3) unknown consequences of various indentifiable factors, and 4) variability of unidentified source.
3. Where possible, identify the organic and non-toxic assimilative capacities of various ecosystem units for each substance with particular emphasis on federal, state, or local laws, standards, and regulations.
4. Determine the models, the processes, and variables which should be available and appear to explain the observable rates of change in the ecosystem with particular emphasis on seasonal successional and trend changes. Determine the models to be used, the cost of computer runs, the driving variables to be used and the range of expected results.
5. Examine the available data and determine whether or not the resolution (e.g. grid size), precision, variability, and consistency are adequate.

6. Determine whether or not the data actually available are likely to be sufficient to make necessary projections in changes of amount of ecological categories, variable values, and process rates. Are all the data necessary? Considerable effort should be made to reduce the original checklist to a small necessary and sufficient set of characteristics.
7. Determine what new data are needed and estimate both the cost and likelihood of obtaining that data.
8. Develop ad hoc analyses appropriate to the site-specific special conditions.
9. Perform the necessary analyses to describe the existing dynamic aspects of the ecosystem with particular emphasis on the projection of the change which will occur without additional human intervention.

DESCRIPTION OF CHANGES ACCOMPANYING EACH PROJECT ALTERNATIVE:

For any facility there may be a number of alternative sitings and potential development patterns. The urban development pattern will have greater and more long-term impacts than the proposed facility on the ecological units and thus on the ecosystem processes. Therefore, the possible development patterns and the impacts from them need to be emphasized in the description.

Chemical, physical, and biological changes constitute inputs to the models describing the ecological variables. The linkages between the planner's ability to predict the developmental pattern, the engineer's ability to project the physical and chemical characteristics which arise from that pattern, and the biologist's ability to predict biological changes and the models which will use these various inputs are still weak. Nevertheless, the state of the art is improving rapidly within each component, and interdisciplinary systems approaches accompanied by appropriate linkages of ecosystem models and model components should improve the ability of the overall process to project changes.

DESCRIPTION OF INCREMENTAL AND SYNERGISTIC EFFECTS

Wastewater treatment facilities and highways and the accompanying urbanization tend to accumulate in pockets and along corridors, streams, or lakes. The incremental effect of one more urbanized area along the stream may be more than that of any single previous unit because of the accumulative impact of materials and energy being added to the ecosystem. Each newly added urban area increases the technological requirements to import resources and export or recycle wastes and places more stress on the ecosystem.

Additionally, when two or more substances are added to a system, synergistic effects (non-additive) are frequently encountered. Thus, the projection of impacts from one type of urbanization will accompany the projected results of other urbanization.

DESCRIPTION OF THE RECOMMENDED ACTION

The sum total of all social, economic, and environmental factors must determine the selection of a specific recommendation for human intervention by means of a public investment in a wastewater treatment facility or highways. The land use and development patterns that result from this recommendation will result in specific inputs to the ecosystem models, which can then be used to describe for the decision-maker the specific ecosystem changes which will follow the recommended action. If the previous sections have been properly presented, the inputs of the final choice should be summarized by reference to graphs, tables, charts, and maps.

REQUIRED OPERATIONAL ADJUSTMENTS WHICH RESULT FROM THE RECOMMENDED ACTION

The decision-maker needs to know the necessary legislative (state, council of governments, county, and city) adjustments to assure that the human capacities of the facility will not be exceeded and produce additional impacts on the ecosystem. Further, he needs to know the ecosystem impacts likely to be encountered if the necessary legislative adjustments are achieved. He needs to know if new technologies are required to protect the ecosystem and the consequencies of failure of these technologies. He needs to know whether or not adjustments are required to provide for the synergistic and accumulative effects indicated by the selected alternative.

SUMMARY

The proposed Space-Time Analysis is designed to emphasize the dynamic nature of the ecosystem. Ecosystems are constantly changing but man's activities may greatly alter the rate of change. The space throughout which the facility will have impact is delineated and described in three dimensions and the projected changes during time are indicated. Projections include the case of no additional human intervention and each alternative intervention.

Existing (on shelf) models, maps, data bases, and regional plans are used to determine the presence and distribution of the ecological units which best describe and identify the potential change. A nesting of ecological units is vital since airsheds, water sheds, and jurisdictional boundaries differ. The description of the existing ecosystem requires a consideration of the structural and functional characteristics, with particular emphasis on cyclic (seasonal) phenomena and on existing trends in the system. Changes in each of the characteristics can be projected on the basis of existing ecosystem and socio-economic trends and because of actions which are already predictable (or at least projectable), e.g., human population growth, ecological succession. The description of the several possible human interventions that would alter the ecosystem should include a comparison of the diverse results which are possible from these alternatives. While the action recommended should follow logically from a discussion of the above factors, the summary should also clearly indicate why "no action" is not satisfactory.

Almost any infrastructure investment and particularly a waste treatment facility or a segment of a highway, makes an incremental contribution to impacts which may not be clearly evident from the impacts of the specific project itself. These incremental effects need to be identified and discussed. Additionally, potential and assured synergistic effects, which will result because of the interaction between various human interventions, should be fully considered.

In its most simplified form, the methodology offered here should be construed by the practitioner as an "overall approach," "a way to view your effort," and/or "as a source of formulating questions to which you will obtain much needed answers."

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A MODEL FOR PROJECTING LAND USES AND THEIR IMPACTS ON ECOSYSTEMS

David P. Carlisle and Richard A. Park*

INTRODUCTION

Under the terms of its contract with the Environmental Protection Agency, The Institute of Ecology was to indicate the feasibility of using the International Biological Program (IBP) modeling experience in assessing the environmental impacts of wastewater treatment facilities (WTF) and highways. The initial review of IBP models suggested that none was directly applicable to the goal of general impact assessment. However, the IBP Eastern Deciduous Forest Biome modeling effort, including both terrestrial and aquatic models, came closest to the goal. Therefore, it was agreed that a terrestrial model based on prior IBP models would be developed for the Lake George, New York, area - one of the Biome sites. The result was LAND (Land-use ANalytical Descriptor).

Because of financial and time limitations, it was necessary to concentrate our research effort on LAND's theoretical structure. The model has been conceptualized and programmed, but it has not been fully calibrated. Although LAND is a generalized model, it is intended only as an example of what can be adapted from existing models at the regional level.

MODELING GOALS

As described in the case study, which was based in part on LAND, any model used in the preparation of an environmental impact statement (EIS) should be capable of application to each step of the space-time analysis (see METHODOLOGY). That is, it should be able to project the effects of: 1) continued developmental trends, 2) development stimulated by the proposed public investment, and 3) further public investment necessitated by the resulting urbanization.

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Furthermore, the model should be capable of the spatial resolution required by the EIS. That means it should yield projections for each drainage basin, ecosystem, and residential and commercial area, taking into consideration site-specific characteristics.

Ideally, the model should represent a melding of land-use changes and ecosystem responses so that subtle, but important, impacts on biotic productivity, diversity, and uniqueness can be projected.

BASIS FOR MODEL

LAND is a manifestation of the IBP modeling philosophy as applied to the goals cited above. Most influential were the land-use transfer approach of Hett (1971), the forest-succession empiricisms of Shugart, Crow and Hett (1973), and the environmental-management perspective of Park, Scavia and Clesceri (1975).

In order to satisfy the spatial requirements for assessing secondary impacts, LAND employs a Km^2 grid. This permits the examination of effects on individual drainage basins, mountains, habitats and villages. It also enabled us to use an existing retional data base, LUNR, which contains land-use data on a Km^2 grid.

The temporal requirements were satisfied by use of a yearly time-step, with calibration data for three time periods at ten-year intervals. These data included the LUNR data, based on 1968 aerial photography,and interpretations of 1948 USDA Soil Conservation photos and 1958 NYS Department of Environmental Conservation photos. Therefore, it is possible to calibrate the model for twenty years and then efficiently run it for fifty years or more.

Ecologic realism was incorporated by using a modification of the forest succession model of Shugart, Crow and Hett

(1973). Furthermore, linear transformations of land-use categories and forest types to animal habitats are being incorporated so that the presence or absence of key species can be projected. By means of known relationships of nutrient loadings to land use and population density (for example, Shannon and Brezonik, 1972) LAND can be linked to the aquatic ecosystem model CLEANER (Park, Scavia and Clesceri, 1975).

STRUCTURE OF MODEL

Development of the model was based on recognition of the fact that both established trends and additional infrastructure investment result in land use changes; these changes are mediated by site characteristics; and the changes, in turn, have a direct or indirect effect on the functioning of natural and agricultural ecosystems.

LAND consists of a series of simultaneous differential equations of simple form. A hierarchy of land-use and vegetational-type transfers is assumed. For each transfer there is a mean transfer rate for the region. Each Km^2 cell is characterized by a variety of environmental, societal, aesthetic and public-improvement attributes; these alter the potential transfer rates for that particular cell. Furthermore, a stochastic element is

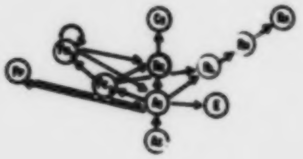

Figure 2-1. Hierarchy of land-use transfers in LAND

introduced to mimic the capriciousness of Man in developing any particular cell.

FORMULATION OF MODEL

As examples of the formulation of the component submodels, let us consider the algebraic equations for natural forest and shoreline residential property. The submodel for natural forest, Fn, is the simplest because it only entails transfers, representing natural succession, from brushland, Fc, and other forest types, Fn_j, and transfers to field, Ai, and pine-oak (depending on soil type) because of fire.

$$Fn_{i_t} = Fn_{i_{t-1}} + \alpha\,(Fc_i) + \alpha\,(Fn_j) - \alpha\,(BURN) - \alpha\,(Fn_j)$$

α = stochastic switch = 0 or 1 depending on comparison
of random number (R) and transition probability
(X) for i^{th} and j^{th} forest types:
    Pine-oak (fire-controlled)
    White pine-hardwoods
    Northern white pine-hardwoods
    Northern hardwoods
for brush (Fc)
and for fire (BURN) returning to inactive
agriculture (Ai) or to pine-oak

The submodel requires the area of natural forest in each Km^2 cell at t = 0 as an initial condition. Each transfer is accomplished using a stochastic switch, α. The switch has a value of 1 for a particular time step if a random number generated by the program equals or exceeds the given transition probability. The function BURN determines whether fire-controlled transfer is back to field (the same as inactive agriculture) or to pine-oak forest, which can recover from fire.

The submodel for shoreline residential property, Rk, is of particular interest because of the impact this land-use category has in the Lake George region. This submodel represents transfers from several land uses: inactive agriculture, natural forest, brushland, and pine plantation. The loss term represents transfer to commercial land use.

$$Rk_t = Rk_{t-1} + \alpha(q)Ai + \alpha(q)Fn_i + \alpha(q)Fc_i + \alpha(q)Fp - \alpha(q)Rk_{t-1}$$

$$\alpha = \begin{cases} 0 \text{ if } R > X \\ 1 \text{ if } R < X \end{cases}$$

R = random number

$X = ((TAVE + TP + f(H) + e^{-\beta DIST} + f(SOIL))(AMNTY))/N$

TAVE = mean transfer rate

TP = regional tourist pressure

H = highway class in cell

DIST = distance from Northway interchange

AMNTY = f(size of lake, water quality)

N = number of LUNR categories in cell:

Ai = inactive agriculture

Fn_i = forest (i^{th} forest type)

Fc = brush

Fp = pine plantation

q = proportion of area transferred

Loss term represents transfer to commerical land use

It can be seen that this submodel, which is representative of most of the submodels, introduces additional complexity in that only a given percentage, q, of a land use or forest type is transferred at one time. However, of far greater implication, the transfer probability is dependent on cell-specific characteristics and can change dynamically during the course of a simulation.

The mean transfer rate, TAVE, is enhanced or reduced by a series of terms. One of these, representing regional tourist pressure, imparts a degree of nonlinearity to the submodel. In our simulations for Lake George it is used as a time-varying term to account for the surge in development following construction of the Northway (I87). There is a function for the class of highway in a given cell and another representing the exponential decay of development pressure away from the Northway interchanges - both can be considered as accessibility terms. The final term is a function of soil type in a given cell and, for poor soils, represents an impediment to development. If the cell is serviced by a wastewater treatment facility this impediment is removed.

There is also a reduction factor, AMNTY, to represent the effect of suboptimal recreational amenity. If the lake is large and has excellent water quality, such as Lake George, then the factor has a value of 1; that is, it does not reduce the transfer rate, which represents developmental pressure. If the lake is smaller, such as several other lakes in the proposed Lake George sewerage district, or if the water quality is objectionable - as indicated by the environmental perception survey - then the factor has a value of less than 1 and the transfer rate is reduced accordingly. Thus, the formulation includes negative feedback. The water quality parameter can be adjusted manually during a simulation; or, eventually, it can be determined dynamically through direct linkage to CLEANER.

FUNCTIONALITIES OF THE MODEL

External

The only explicit external functionality in the model is what we have termed regional tourist pressure (see Shoreline Residential Property above). Although we have used it as a step function to represent the effect of opening the Northway, it could be used as the means for driving the model. For example, it could incorporate the effects of changing affluence and increasing population density on development (see Stern, 1971; Park, Scavia and Clesceri, 1975).

Environmental

In our study we have recognized soil types, slope, depth to bedrock, depth to water table, floodplain, and susceptibility to fire as important cell-specific characteristics. Most of these are represented in the transfer-rate terms. Drainage basin and predominant forest type were also noted for each cell.

Societal

The developmental constraints of local zoning ordinances are considered in the model. Also, because of the location of part of the study area within the Adirondack Park, the Adirondack Park Agency comprehensive land-use and development plan was incorporated as an additional set of constraints.

Implicit in the SOIL function is the partial control exerted by county health regulations on developments requiring septic systems in areas of soils with poor percolation characteristics. This constraint is removed when the areas are incorporated in a sewerage district.

Aesthetic

Lake size and water quality are important factors in the submodel for shoreline residential property. We intend to incorporate scenic vistas and gravel pits as aesthetic characteristics that can change dynamically during a simulation. Proximity to state parks and other public recreational areas might also be considered. Likewise, if time had permitted, we would have used the presence of major utility lines as negative amenities affecting residential development.

Public-improvement

The effects of transportation are a major functionality in the model. Each cell is characterized by the highest class of road that occurs (excluding the interstate system), and that contributes to the developmental pressure on the cell (see Formulation of the Model). The interstate highway is treated separately; distance to nearest interchange and regional tourist pressure due to construction of the Northway are important in simulating the Lake George region. These transportation effects can be altered; therefore, LAND has excellent potential for examining the secondary impacts of proposed highway construction.

The secondary impact of a new wastewater treatment facility is manifested principally through the cell-specific SOIL function (see "Societal" above). Development is permitted in areas where otherwise it would be severely limited, and higher density housing and commercial building is allowed in other areas, subject to zoning constraints.

Ecologic

Old field succession is an important part of the model. The planting of pine plantations is also handled explicitly. However, most of the ecologic functionalities are derived from the land-use and forest-type categories.

Habitat for each of a variety of animals, including rare and endangered species, is determined through a linear transformation of key categories. For some field-dwelling animals, such as woodchucks, these categories include interstate highway and utility right-of-ways. The assumption that presence of required habitat implies presence of the species, excluding deer and other heavily hunted wildlife, is supported by many wildlife biologists. And even deer can be predicted from land-use categories with some degree of confidence (Bergstrom, 1975). For some widely ranging species, including bear, deer, coyote, and fisher, the contiguity of habitat is important; LAND is programmed to perform this "bookkeeping" function efficiently.

The principal drainage basin corresponding to each cell is encoded, and trout streams are also designated. With little additional effort LAND can be adapted so that changing nutrient and siltation loadings can be projected. These, in turn, can be used to predict impact on trout. Nutrient loadings in drainage basins emptying into the larger lakes such as Lake George and Glen Lake can be used to drive CLEANER in simulating these lakes. For smaller bodies of water Vollenweider's productivity model could be used to project water quality.

DATA PROCESSING

In order to run LAND for the Lake George region it was necessary to have land-use and vegetational data for each Km^2 cell for at least two, and preferably for three, distinct time periods. For this reason the existing LUNR data base (1968 photography) was checked for errors, 1948 and 1958 aerial photographs were interpreted, and additional data were obtained (see Case Study).

The first step was to visit the site to gain a first-hand understanding of accessibility, land-use patterns, forest types, successional stages, eutrophy, and topographic corridors and impediments. For one month we had the services of Paul Marean, a graduate biologist with extensive field training. A significant portion of his time was spent in obtaining "ground truth" for use with the LUNR photographs and overlays and the NASA U-2 color infrared photographs (see Case Study).

Obvious errors in the LUNR data were corrected and inconsistencies in interpretation were taken into consideration. The high-resolution color infrared photographs were used to map the principal forest types, yielding an invaluable disaggregation of the LUNR natural forest category.

Interpretation of the 1948 and 1958 aerial photographs was facilitated by comparison with the LUNR overlays for 1968. Scale differences were resolved by the construction of Km^2 grids on mylar overlays for each of the photo sets. Registration of the grid with the standard U.T.M. grid was accomplished through comparison with a set of USGS topographic maps, using easily determined landmarks. The grid was varied to account for obvious parallax distortions of scale.

All the photographs were interpreted by one individual (Marean) in order to minimize inconsistencies. Data were entered directly onto coding forms and keypunched in a format that was most convenient for the interpreter. Computer routines were used to detect errors in interpretation, especially land uses that did not sum to unity for a particular cell, and errors in coding, involving misplaced data. The data were then reformatted to be compatible with the LUNR data.

CALIBRATION

Mean transfer rates (general transition probabilities) for each pair of categories were obtained for each ten-year time interval by subtracting the 1948 dataset from the 1958 dataset and from the 1968 dataset and averaging the results respectively. Comparison of these "SUBTRAX" values with twenty-year transfer rates, obtained by subtracting the 1948 dataset from the 1968 dataset, indicated the nonlinearities in external developmental pressure. These determined the time-varying values of TP, the "tourist pressure" parameter. The twenty-year rates determined the TAVE values.

Given sufficient time we could have statistically partitioned the variance in transfer rates to account for cell-specific differences. In fact, we purposely chose a larger area for calibration than was needed for the EIS in order to obtain a statistically valid sampling of cell characteristics and transfer rates. However, we have had to be content with a "brute force" calibration.

The initial set of coefficient values was derived from subjective inspection of the transfer patterns. The inspection process was facilitated by having PLANMAP output (see Case Study) for each time period, as well as SUBTRAX PLANMAP output.

We are still performing the calibrations. However, our procedure is to run the simulation for a ten-year (or twenty-year) period and express the results as PLANMAPs which can be compared with the PLANMAPs of the observed land uses and vegetational types. The coefficients are altered accordingly and the process repeated until the resulting PLANMAPs converge with the real-world. Therefore, through subtle manipulations of the coefficients for the various functionalities the cell-specific responses can be derived.

VALIDATION

Data were obtained for the adjoining Schroon Lake area, but have not been used in the calibration. When we are satisfied with the calibration, these data will be used to test the validity of the model. It is anticipated that some further adjustments in the coefficients will be necessary to match the simulations to this independent dataset. Without such an evaluation and subsequent "fine tuning" we would not be able to place any confidence in the use of the model for projecting future changes. Validation with an independent dataset is essential if modeling is to become a useful tool in assessing environmental impact.

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MAN'S IMPACT ON THE ECOSYSTEM

David L. Jameson

Any perturbation to any part of the ecosystem will have repercussions throughout the rest of the ecosystem. Although this principle applies to structural components of the ecosystem, it is especially true of the functional components. Life on earth depends on the flow of energy and the cycling of materials through the ecosystem. The abundance of organisms, their metabolic rates, and the complexity of their interrelationships are all controlled by these two factors. Energy and materials flow through the biotic environment inseparably as organic matter. But the flow of energy is one-way while nutrients recirculate within and between ecosystems. "The continuous round trip of materials, paid for by the one-way trip of energy, keeps ecosystems functioning." (Smith, 1974).

Humans are an integral part of any ecosystem but human activity is a more pervasive force than is the case with other organisms. Maintenance of a quality environment requires actions to be perceived in the light of their effect on the internal dynamic and regulating mechanisms of those ecosystems (Reichle, 1975, Reichle, et al., 1976). Humans divert energy, water, and other materials from natural systems in order to create unstable, artificial systems distinguished by high energy inputs and turnover rates (and in some cases, lowered species diversity and low stability). In brief, many of human systems are typical of simple early developmental stages of succession (Gill and Bonnett, 1973)

Humans have significantly modified their physical environment by large scale removal of plant cover via filling, logging, burning, land drainage or inundation, earth moving, and resource extraction. In some cases this devegetated land is then covered with concrete or other rock-like material, resulting in greatly increased heat-holding capacity and reduced poroxity. Such practices can increase ambient heat energy and surface water run-off rate, conditions already aggravated by devegetation and fossil fuel combustion respectively. Other often mentioned impacts include: lowering of ground water levels, reduction in exposed water surfaces (marshes, wetlands, etc.) and weather and climate modification (lowered humidity, reduced radiation and increased frequency of light rainfall). Perhaps the most talked about impacts on natural systems are those resulting from the practice of dumping into the air and water over 500,000 organic and inorganic, natural and synthetic, biodegradable and non-biodegradable substances which often disrupt or accelerate many of the processes so vital to ecosystem function.

IMPACTS OF URBANIZATION ON AGRICULTURAL ECOSYSTEMS

An intensive agricultural system has some unique properties which distinguish it from other terrestrial ecosystems. Maximum economic productivity is obtained by the development of a monoculture and the provision of external energy, materials and, water. Since the detritus component is destroyed by the exposure to a wide range of temperatures and the continual disturbance of the soil, there is little assimilative capacity. Materials not converted to plant productivity are washed into nearby streams where they contribute to the productivity of the aquatic ecosystem. Thus the conversion of agricultural land to urban property can result in a change in nutrient cycling and material flow different from those changes which occur when forest is urbanized.

Abandoned agricultural land will return to the natural state by successional stages which are well studied and familiar to most ecologists but which vary extensively within the Eastern Deciduous Forest Biome depending on local climate, soil and, vegetation. Agricultural productivity near areas with rapid urbanization tends to decrease because of economic factors more than because of losses from urban pollution. Ozone (Coulson and Heath, 1974), SO_2 (O'Connor and Parbery, 1973; LeBlanc and Rao, 1973) SO_2 and NO_2 (Barrett, Hill, Hill and Lamb, 1974), Fl (McNulty and Newman, 1958) and other gases have been identified in the reduction of plant production; when some of these same gases are in low concentrations, they serve as stimulants (Bennett and Resh, 1974). Some crop damage can be correlated to particular pollution sources and some economic losses may be attributable to general urban air pollution, but the unique local factors control and each situation requires separate study.

As agricultural land is replaced by urban land uses the first influence is that of the invasion of weekend and gentlemen farmers who work in the city and live outside the city. The diversity is increased by the addition of a wide variety of introduced species. Successional stages of old fields further increases the variety of plants and the increase in diversity of animals follows. Changes in human population, age distribution, continuing urbanization, and changing economic factors results in the eventual conversion of the land to suburban use.

Currently there are approximately two acres of cropland and two acres of rangeland for each person in the United States (Lanier, 1970). Loss of acres of agricultural land to urbanization will result in expansion of cropland, usually at the expense of rangeland and sometimes at the expense of natural areas. Most urbanization in the U.S. today removes cropland but each local situation is unique.

In summary, there are few general principles available to determine the loss of crops from urbanization. Each situation can be assessed on the basis of comparing crop productivity near an urban area with that further from it and using comparison of these data with the predicted urbanization developmental pattern to estimate the crop loss which will occur accompanying any given WTF or highway. The overall incremental loss of cropland becomes more important as more natural and rangeland is lost and as these fininte resources become more valuable.

IMPACTS OF URBANIZATION ON ECOSYSTEM PROCESSES

The part of the urban environment which accomodates commerce and industry is most often thought of in connection with environmental impacts, for here many human activities are concentrated.

A city together with its built-up suburbs can be regarded as an ecosystem importing food, water, fossil fuels, and raw materials, and exporting sewage, combustion products, and solid waste. Normal ecosystem processes exist in highly modified, artificial forms or operate highly stressed conditions.

Primary productivity is adversely affected by reduced light from dust haze, reduced humidity, low soil moisture, acid rain damage to plant tissues (Thomas, 1965), and acid rain inhibition of the microbial and invertebrate activity which makes nutrients available (Satchell, 1967). Photosynthesis is inhibited by a number of gases found in urban air (SO_2, O_3, HCN, HF, PAN, ethylene, NO_x, SO_x, etc.) Increased frequency of light showers results in shallow roots and plants easily toppled by wind. Artificial lighting causes flowering at different times and increased tempertures lengthens the growing season.

Many restrictions are placed on photosynthesis and production by concrete and particulate matter in the air of the urban environment. Because of intense fertilization, suburban areas may be more productive than natural areas (Lawson et al., 1972). The surplus biomass of the urban environment is not allowed to accumulate, compost, and fertilize urban areas; it is hauled away as waste and chemical fertilizers applied. In a similar way biogeochemical cycles in urban support areas (wastershed, forests, farms, etc.) have been modified by resource removal.

Since most urban development has occurred near water, coastal areas have been greatly modified by draining and filling to create more land. Extensive sections of rivers have become open sewers. The large amounts of organic matter now being introduced into waterways overload the cylying capacity of these systems; deplete O_2 levels, initiate algae blooms and generally accelerate eutrophication. Although less drastically polluted water may have greater productivity because of extra heat and nutrients, such inputs usually result in the simplification of aquatic communities. Species of early successional stages are common and productivity is high.

Unfortunately, urban waste is not confined to sewage. Heavy metals and persistent biocides now contaminate all waters. Construction and other types of disturbances typical of the city cause erosion and siltation. Urban street runoff adds oil, grease, deicing compounds, road marking paint, detergent, significant amounts of animal excretion (Beck, 1973), and pesticides to aquatic systems. Urban pesticide levels have been found to be higher than rural levels (Tarrant and Tatton, 1968).

The effects of pollution are not confined to aquatic mineral cycles. Acid soil restricts earthworms, reduces availability of certain nutrients, and restricts microbial and enzymatic action in soil. Invertebrate reducers, which play a significant role in the decompositon process, may find living sites very limited in the inner city and are inhibited by pesticides in the suburbs (Barnes and Weil, 1944). The urban ecosystem contrasts with most natural ecosystem, which use and reuse many elements. Natural systems may permit abundant elements to pass-through as part of a long term sedimentary cycle but they are much more conservative with such scarce elements as phosphorus. An urban ecosystem not only dumps elements recycled by natural ecosystems, it also dumps metals and other substances which could serve as raw materials for industry. Putting it simply, an urban ecosystem is one which does not reuse its waste.

Measurements of biotic diversity do not tell us very much about cities that we did not know already. In cities, man is the dominant species, accompanied by a few tough plants and scavenging animals. Although suburbs have been found to have a high degree of plant diversity, (Lawson, et al, 1972), the ornamentals responsible for this diversity are usually exotics, protected by sprays, and enhanced by protected habitats and fertilizers. Consequently, interaction with natural food chains is altered (Recher, 1974) and these ornamentals may provide little reinforcement of stability.

The city replaces a large component of a more naturally functioning ecosystem with a very specialized and highly managed urban ecosystem in which the activities of a single animal species (man) and his urban correlates (starlings, dogs, and cats) replace more diverse animal systems which are less dominated by man (agricultural, forests, ponds, and streams). These man centered activities alter air and water quality, modify weather, produce solid waste, noise, radiation, hazardous substances, change the soil, hydrology, climate, plant and animal communities, and use considerable fossil fuel energy. Each of these activities, and the urban structure itself, influences the productivity of both the managed (agricultural, commercial forest) and the unmanaged wildland ecosystem which surrounds the city.

Additionally, there are some natural forces which impact near city ecosystems differently when compared to far from city habitats. Ice storms, hurricanes, subsidence effects, have site specific characteristics. Both natural and agricultural habitats are impacted by human interventions which vary considerably. Vandalism of farm crops and rustling have higher frequencies near cities. Cities provide dust, noise, odor, and ferial dogs and cats which will influence agricultural productivity and ecosystem function. Recreational activities including snowmobiles, trail-bikes, dune buggies, and even traditional horseback riding and hiking can impact areas near cities.

Coleman (1975) has pointed out the relation between diversity and biological productivity, and land use patterns. Near the city center, productivity and diversity are very low. The older residential areas near the city center have higher diversity and productivity than newer residential areas. When range or agricultural acreage are first removed from economic productivity and when the city first begins to invade the natural forest, both biological productivity and diversity are reduced. The gentlemen farmer with his large lots and higher income will increase diversity by importation of fruit producers, ornamentals, and exotics, but his activities will have little influence on biological productivity.

Berry, et al. (1974), reviewed the relation between environmental quality and the type and density of urbanization. This volume is a valuable source of trends and correlations in data from existing cities. The "Costs of Sprawl" provides estimates of the changes in environmental quality which will accompany various planned and unplanned development patterns.

Urbanization impacts the ecosystem by perturbating the rates of various ecosystem functions. To understand these changes, we need to study areas before urbanization, during the process of development, in areas with relatively stable urban structure, in areas with urban decay, and with urban renewal. The complete cycle has not been studied in a single situation. Comparative studies provide some indications, and studies of each step in the process are scattered through the literature. However, these studies emphasize the easily measured parameters (e.g. water quality) rather than the much more significant measure of the impact that changes in parameters have on the ecosystem.

Borman et. al. (1974) studied particulate and dissolved matter export and the erodibility before and after deforestation. Dissolved substances were approximately twice as much as particulate matter in the mature forest but rose to more than eight times as much during the first two years following cutting. Erosion increases after two years and particulate matter output rises sharply from 2.5 metric tons per square kilometer per year to 38 metric tons per kilometer square per year. Richards and Leonard (1973) discuss some of the problems associated with fertilization of urban forestry and recreation developments. They point out that many species depend on low nutrients and fertilization and provide useful cover while fertilization may promote the growth of noxious weeds and increase maintenance costs. Richard (1974) has pointed out that more of urban greenspace will be recycled from dumps, urban renewal, etc., and urban forests provide promising structures to redeveloped balanced ecosystems.

Baumann et al. (1974), reviewed the development of urbanization at Lake Wingra, Wisconsin from 1837 to 1973. The lake has been reduced in size by almost one third by swamp and marsh drainage and park development. A number of plant and fish species have disappeared, and introduced forms have become common. In general, the lake management has been to respond to single problems rather than with a consideration of the entire ecosystem. Lawson et al. (1972), compared the structure and primary productivity of two watersheds in the Lake Wingra basin. Residential activity greatly increased the number of species of herbs, shrubs, and trees, increased the productivity of herbs, and slightly decreased the productivity of trees and shrubs. The natural area had more shrub cover and higher trees density (p. 2-48).

Huff et al. (1973), estimate that 84% of the dissolved inorganic phosphorus entering Lake Wingra is brought in via storm drains even though they contribute only 25% of the total inflow volume to the lake. They used a hydrologic transport model to simulate surface flow rates and volumes for both urban and natural portions of the Lake Wingra basin and estimate changes in runoff composition as land is converted from natural to urban conditions. An atmospheric transport model (Mills and Reeves, 1973) may be useful for the movement of trace contaminants from emission as air pollutants through depositon and subsequent hydrologic transport to streams and groundwater and to predict effects of urbanization on surface flows and associated water quality.

Jameson (1971) compared parts of the San Jacinto River watershed with and without small towns along the branches of the river. Standard water quality measures were not significantly different at stations ten or more miles downstream on branches with small towns (2) and those without (7). Urbanization, vegetation, soil and weather were used as predictor variables to water quality criteria measures and analyzed with canonical correlation analysis. The amount of urbanization was not a significant predictor to water quality in areas with little urbanization. Waste treatment practices determined water quality in areas with high density urbanization.

TABLE 3-1. LAKE WINGRA

ECOLOGICAL PARAMETER	NOE WOODS	NAKOMA RESIDENTIAL
Total Above Ground Productivity $g/m^2/yr$ (adjusted for impervious services)		
Trees	811.8	1009.8
Foliage ($g/m^2/yr$)	410.8	319.4
Branches ($g/m^2/yr$)	72.5	87.4
Bole ($gm/m^2/yr$)	282.4	305.3
Shrubs ($gm/m^2/yr$)	28.0	40.0
Herbs ($gm/m^2/yr$)	18.1	257.5
Number species shrubs	12	74
Percent cover shrub	40	20
Number species trees	11	75
density of trees (stems/ha)	422	143
mean basal area trees D.B.H.	15-16	22-23

Data from Lawson, G. J., G. Cottam, and O. L. Loucks, 1972. Structure and primary productivity of two watersheds in the Lake Wingra basin. EDFB memo report #72-98

Turner et al. (1975), compared two similar size watersheds in Florida representing natural and urban areas. Suspended and dissolved solids and dissolved nitrogen were higher in the urban watershed than would be predicted by the higher stream discharge. Phosphorus was near expected and silicon was lower than would have been predicted from the forested watershed.

Lake George, N.Y., has been studied extensively by various IBP projects and has served as a focus for one of the case studies of this project. Drs. N. Clesceri and J. J. Ferris have studied nutrient budgets for nitrogen and phosphorus from disturbed and undisturbed watersheds. The seasonal cycles are clearly shown in the accompanying tables (pp. 2-50 thru 2-54). Additionally, they have provided us with some tables showing comparative data from other studies. Studies at Lake George suggest that almost a third of the phosphorus comes from septic tank effluents, a third from forest runoff, and a third from precipitation. Lawn fertilizer contributed only 2.6% of the phosphorus and 1 percent of the nitrogen while septic tanks (4.8%) and sewage treatment plants (9.1%) make significant contributions to the nitrogen. Much of the phosphorus (73.8%), and nitrogen (68.8%) are retained in the lake sediments. The influence of perturbation on the pelagic ecosystem model is shown in the figure from Scavia, D. (1974) (p. 2-55).

These are awesome impacts on ecosystem function because humans are now and will ever be dependent on the functioning of the ecosystem. Most of human existence has been lived as a hunter-gatherer -- a part of the natural ecosystem. Primitive agriculture allowed manipulation of the natural ecosystem to increase production with the help of animal energy and irrigation. The technological agriculture of today completely transforms the natural ecosystem, and places society largely outside of the natural food chain and biogeochemical cycles. Maintenance of highly productive monocultures requires huge expenditures of energy (largely in the form of fossil fuels) for mechanization, fertilization, pest control, and development of hybrid crop varieties. Ultimately, we are still dependent, as are all

TABLE 3-2. MONTHLY NUTRIENT BUDGETS FOR N and P IN NORTHWEST BAY BROOK WATERSHED, LAKE GEORGE, N.Y.*

	Nitrogen (g/ha)			Phosphorus (g/ha)		
Month	Input	Outflow	Net	Input	Outflow	Net
June	732.3	101	+ 631.2	26.7	3.7	+ 23.0
July	962.7	108	+ 854.7	73.9	4.7	+ 69.2
Aug.	533.2	203	+ 330.2	7.4	5.9	+ 1.5
Sept.	917.3	55	+ 862.3	2.4	0.9	+ 1.5
Oct.	456.1	67	+ 389.1	3.1	1.6	+ 1.5
Nov.	1108.4	273	+ 835.4	67.4	8.0	+ 59.4
Dec.	1134.8	96	+1038.8	43.8	8.3	+ 35.5
Jan.	541.7	511	+ 30.7	16.6	7.8	+ 8.8
Feb.	969.2	167	+ 802.2	29.5	2.4	+ 27.1
Mar.	1258.2	280	+ 978.2	32.2	7.4	+ 24.8
Apr.	967.2	298	+ 669.2	7.0	13.2	- 6.2
May	1866.2	235	+1631.2	4.5	3.8	+ 0.7
Totals	11447	2394	+9053	314	67.7	+246.8

* THIS WATERSHED IS REPRESENTATIVE OF FORESTED (UNDISTURBED) ECOSYSTEMS

THIS TABLE PROVIDED BY N. CLESCERI AND J. J. FERRIS

TABLE 3-3. MONTHLY NUTRIENT BUDGETS FOR N and P IN HAGUE BROOK WATERSHED, LAKE GEORGE, N.Y.*

	Nitrogen (g/ha/mo)			Phosphorus (g/ha/mo)		
Month	Input	Outflow	Net	Input	Outflow	
June	616.6	59	+ 557.6	22.5	2.7	+ 19.8
July	811.4	60	+ 751.4	62.3	2.1	+ 60.2
Aug.	449.6	143	+ 306.6	6.2	4.2	+ 2.0
Sept.	771.5	35	+ 736.5	2.0	1.2	+ 0.8
Oct.	380.7	55	+ 325.7	2.5	2.0	+ 0.5
Nov.	933.2	99	+ 834.2	56.7	7.3	+ 49.4
Dec.	1081.4	122	+ 959.4	36.9	5.0	+ 31.9
Jan.	456.5	513	- 56.5	13.8	16.3	- 2.5
Feb.	813.9	561	+ 252.9	24.9	39.0	- 14.1
Mar.	1060.7	258	+ 802.7	27.2	4.5	+ 22.7
Apr.	813.2	143	+ 670.2	5.8	11.6	- 5.8
May	1573.7	199	+1374.7	3.8	9.1	- 5.3
Totals	9762	2247	+ 751.5	264.6	105.0	+159.6

* THIS WATERSHED IS REPRESENTATIVE OF DISTURBED ECOSYSTEMS

THIS TABLE PROVIDED BY N. CLESCERI AND J. J. FERRIS

TABLE 3-4. MONTHLY NUTRIENT BUDGETS FOR N and P IN WEST BROOK WATERSHED, LAKE GEORGE, N.Y.*

	Nitrogen (g/ha/mo)			Phosphorus (g/ha/mo)		
Month	Input	Outflow	Net	Input	Outflow	Net
June	732.2	376	+ 356.2	26.7	6.5	+ 20.2
July	962.7	427	+ 535.7	73.9	4.2	+ 59.7
Aug.	533.2	992	- 458.8	7.4	6.2	+ 1.2
Sept.	917.3	489	+ 428.3	2.4	2.2	+ 0.2
Oct.	456.1	532	- 75.9	3.1	1.8	+ 1.3
Nov.	1108.4	962	+ 146.4	67.4	4.0	+ 63.4
Dec.	1134.8	559	+ 575.8	43.9	7.3	+ 36.6
Jan.	541.7	743	- 201.3	16.6	14.2	+ 2.4
Feb.	969.2	405	+ 564.2	29.5	3.0	+ 26.5
Mar.	1258.2	985	+ 273.2	32.2	11.3	+ 20.9
Apr.	967.2	681	+ 286.2	7.0	13.5	- 6.5
May	1866.2	441	+1425.2	4.5	7.5	- 3.0
Totals	11447	7592	+3855	314	81.7	+232.3

* THIS WATERSHED IS REPRESENTATIVE OF DISTURBED ECOSYSTEMS

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TABLE 3-5. NUTRIENT BUDGETS FOR N and P IN PRECIPITATION AND RUNOFF

	Nitrogen (kg/ha/yr)			Phosphorus (kg/ha/yr)		
Location	Input	Outflow	Net	Input	Outflow	Net
H. J. Andrews Experimental Forest #10, OR**	0.99	0.48	+ 0.51	0.27	0.52	- 0.25
L. Sammamish, WA Issaquah Creek Watershed*	----	----	------	0.51	0.87	- 0.36
L. George, NY						
Hague Brook Watershed*	9.76	2.25	+ 7.52	0.27	0.11	+ 0.16
West Brook Watershed*	11.45	7.59	+ 3.86	0.31	0.08	+ 0.23
NW Bay Brook Watershed**	11.45	2.39	+ 9.06	0.31	0.07	+ 0.24
L. Wingra, WI*	8.32	4.49	+ 3.83	0.24	0.54	- 0.30

* DISTURBED

** UNDISTURBED

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TABLE 3-6. DISSOLVED NUTRIENT EXPORT FROM FORESTED (UNDISTURBED) AND DISTURBED ECOSYSTEMS

	UNDISTURBED		
	Outflow (kg/ha/yr)		
Area	N_{total}	P_{total}	Reference
H. J. Andrews Experimental Forest #10, OR	0.48	0.52	Fredericksen, 1972
Hubbard Brook Experimental Forest, NH	2.3*	0.01	Likens & Bormann, 1972 Hobbie & Likens, 1973
Ontario, Canada	2.3*	0.16	Schindler & Nighswander, 1970
L. George, NY Northwest Bay Brook Wastershed (6/1/72 - 5/31/73)	2.39	0.068	Gibble, 1974

	DISTURBED		
	Outflow (kg/ha/yr)		
Area	N_{total}	P_{total}	Reference
Hubbard Brook Experimental Forest, NH	120*	0.02	Likens & Bormann, 1972 Hobbie & Likens, 1973
L. Mendota, WI	3.0	0.36	Lee, 1966
L. Sammamish, WA (Drainage basin sub watersheds)	---	0.5 (ave.)	Welch, et al., 1975
Issaquah Creek	---	0.87	Welch, et al., 1975
L. George, NY			
Hague Brook Watershed	2.25	0.11	Gibble, 1974
West Brook Watershed	7.59	0.08	Gibble, 1974
Urban Lands	6.8 to 8.8	1.1 to 5.6	Loehr, 1974
Forested Lands	1.4 to 3.3	0.03 to 0.9	Loehr, 1974

* NH_4-N+NO_3-N only

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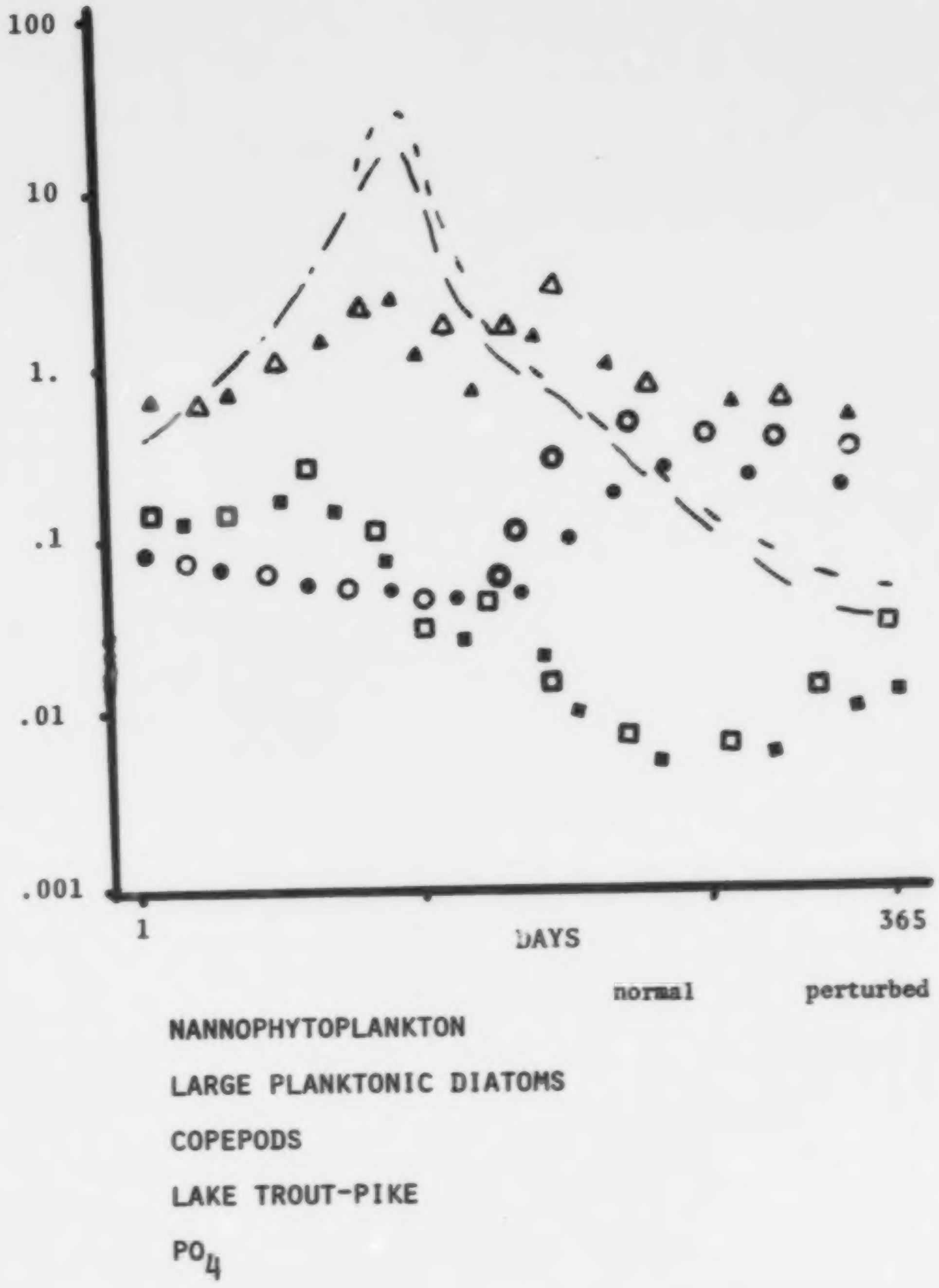

Figure 3-1. Biomass (g dry wt/m^2) of normal and perturbed ecosystem model.

organisms, on plants' ability to fix the sun's energy and produce food and fiber. Even the fossil fuels which account for most of the productivity of agricultural systems are the product of long dead vegetation.

Humans rely on the productivity of the ecosystem for food, housing, and fuel. This requires the huge purifying sink of the earth's ecosystems to decompose and recycle human wastes. However, humans have seriously upset biogeochemical cycling by removing nutrients from some systems (usually terrestrial) and concentrating them in others (usually aquatic). Humans have overburdened the ecosystem's ability to handle the recycling of natural substances and further complicates matters with synthetic materials which the system cannot biodegrade. Such damage to the ecosystem not only affects its ability to assimilate wastes but may affect energy flow and productivity.

Natural ecosystems represent more than a source of organic matter and a sink for wastes. They are the ultimate source of all resources both physical and biological. Physical resources such as air, water, soil, open space, are disappearing or being altered by humans to the point that they can no longer function as they once did in the natural ecosystem. Biological resources -- gene pools -- are also disappearing as species populations and genes become extinct resulting in the loss of these genetic resources to future plant and animal breeding (Terborg, 1973). Bella and Overton(1972) have suggested that environmental planning should emphasize a "strategy of preserved diversity." Westman (1972) has noted the contrast between the value systems of those who emphasize technology and those who emphasize ecosystem analysis in the formulation of legislation and management programs. He questions the usefulness of the concepts of assimilative capacity and of carrying capacity in providing adequate protection for the human ecosystem. Clearly, the goals established by the Congress in the clean water act are not to be achieved without greater emphasis on ecosystem analysis. Several studies have emphasized the importance of approaching man's urbanization process using systems approaches. Stearns and Montag (1974) used what they considered an holistic approach and considered goals, components and processes as a basis for a series of case studies and conclude that there is an urban ecosystem which warrents analysis. Linville and Davis (1976) examined the environment as a political issue in urban government and call for an ecosystems approach to planning and management. Clearly, human activities can impact agricultural productivity, aesthetic values, recreational activities, life styles, industrial capability and the ability of man to respond to changing circumstances. The ecosystem, a basis of all living processes, requires further analysis and study.

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MODELING AND ANALYSIS OF ECOSYSTEMS

Vicki Watson and David L. Jamson

The analysis of ecosystem program was the most ambitious of the U.S. contributions to the International Biological Program (IBP). It began formally in May, 1967, with a grant from the National Science Foundation (NSF). Initially, the goals of the biome studies were stated as follows:

> achieve an understanding of ecosystem operation;
> investigate relationships between land and water systems in watersheds;
> improve estimates of productivity in U.S. biomes;
> add to scientific basis of resource management (U.S. participation in IBP).

To achieve these goals, an integrated approach to ecosystem research was adopted. An ecosystem has been defined (Johnson et al., 1973) as "A community and its (living and nonliving) environment considered collectively; the fundamental unit in ecology." The ecosystem functions as a system in the exchanges of materials and energy. It may be considered to have self-regulatory attributes, may have arbitrarily identifiable boundaries, and certainly has recognizable relationships between subcomponents. The properties of each ecosystem arise from postulated interactions, feedbacks, and synergisms between components of the system and between that system and others. The variables, the processes operating on them, the parameters regulating the processes, and the environmental influences on the system need to be defined and evaluated.

Variables are the individual organisms or populations, the energy, water, elements, soil, physical factors, etc. The *processes* are biological and physical activities that move or transform the materials of the system. Processes may operate within variables (e.g., respiration within an organism or population) or they may be links between variables (e.g., water and nutrient uptake from soil) measured as rates. The relevant *parameters* are coefficients in statements of relationships between state variables and within processes. Some are constant and some vary with the environment. The relevant *environmental factors* limit or accelerate the system by influencing process rates.

Some processes investigated by the biome studies are:

PLANT PROCESSES

Uptake: Net Carbon fixation, water uptake, nutrient uptake

Growth: Vegetation growth, translocation

Life process: Respiration, flowering nonherbivorous mortality

Losses: Transpiration, foliar leaching, sloughing

ANIMAL PROCESSES

Uptake: Food consumption, respiration

Growth: Assimilation, individual growth and development

Life process: Respiration, reproduction

Losses: Excretion

WATER-RELATED PROCESS

Input: Rainfall
Flows: Runoff, runon, infiltration

Losses: Evaporation, percolation to groundwater

NUTRIENT PROCESS

Inputs: Deposition, nitrogen fixation

Transformations: Humification, volatization, ammonification

Losses: Denitrification, decomposition, nitrification

Ecosystem models are listed in Kadlec (1971), O'Neill, et al. (1972), and Parker and Roop (1974). Since the final reports of the U.S. I.B.P. are still in preparation, much of the documentation must be obtained from reports available from the I.B.P. offices at the Oak Ridge National Laboratory.

ECOSYSTEM SUBMODELS (COMPONENT PROCESS MODELS)

The work of IBP dealt with ecosystem metabolism -- the means by which structural characteristics and system properties controlled energy flow, nutrient cycling, and responses to perturbations. Such analysis requires sophisticated mathematical analogs or models of the system, and such modeling played a major role in the biome studies. Recent advances in systems science were also used to advantage by IBP.

In addition to the progress made in systems modeling and analysis, IBP developed a national biome data base and did much to advance the understanding of ecosystem productivity and the role of physical and chemical parameters and related processes in the ecosystem. In fact, during the first two years of the forest biome work, the major emphasis was placed on the development of component process models describing productivity and physical and chemical parameters and processes.

In the Eastern Deciduous Forest Biome, which will serve as our example of the IBP work, productivity research was aimed at four questions:

What are the actual and potential amounts of primary production for certain types of forests in the eastern United States?

How do environmental factors regulate and ultimately limit forest productivity?

How are primary production processes coupled to system processes?

With an understanding of the underlying control mechanisms, can this knowledge be incorporated into mathematical models that permit examination of the system as a whole and thus indicate the consequences of forest ecosystem management? (U.S. participation in IBP)

The following is a partial list of the process models which have been developed. Abiotic: Steady state stand energy (Murphy, Knoerr); Dynamic stand energy (Murphy, Mankin, Knoerr); Soil-litter-atmosphere (Murphy); Canopy energy flux (Hutchison, Matt).

Terrestrial Primary Production: Leaf photosynthesis (Sinclair); Steady state photosynthesis (Goldstein, Mankin); Canopy photosynthesis (Sinclair, Murphy, Knoerr); Plant-water relations (Sinclair, Murphy); Biomass distribution (Ralston, Chapman, Kinerson); Foliage distribution (Kinerson, Higginbotham, Chapman); Branch and stem growth (Kinerson, Chapman); Stand primary production (Goldstein, Harris, Mankin); Stand development (Dinger, Taylor); Succession (Shugart, Johnson, Hett, Crow) Land use dynamics (Hett).

Terrestrial Secondary Production: Population dynamics (Dean); Insect consumption (Goldstein, Van Hook); Stochastic population model (O'Neill); Food chain kinetics (Shugart, Mankin); Terrestrial consumers (O'Neill, Mankin).

Terrestrial Decomposition: Earthworm-litter decomposition (Sollins, Reichle); Nutrients in arthropods (Gist); Arthropods in white pine (Cornaby, Waide); Decomposition by Cryptozoa (Reichle, Van Hook, O'Neill); Soil microinvertebrates (McBrayer); Soil fungal decomposition (Ausmus); Bacteria- substrate (Todd, Gist); Litter decomposition (Cromack); Terrestrial decomposition (Shugart, Mankin).

Terrestrial Nutrient Cycling: Soil nitrogen (Endelmann, Northup, Huges, Keeney, Boyle); Nitrogen budget model (Harris); Soil nutrients (Henderson, Shugart, Goldstein).

Hydrology: Soil water infiltration (Miller, Reeves); Water balance in soils (Murphy); PROSPER - Stand water balance (Goldstein, Mankin); Lake George hydrology (Colon, N. Clesceri); Lake level model (Huff, Dettmann); Lake circulation (Hoopes, Patterson); Seiche movement (Stewart); Mixing model (Park, Silver, Katz, Sterling); Sedimentation (Fox, Park); Stream flow (Curlin, Henderson, Sheppard).

Aquatic Primary Production: Phytoplankton kinetics (Stross, Bloomfield, Koonce); Nutrient-phytoplankton dynamics (Koonce); Aquatic macrophytes (Titus, Adams, Weiler, O'Neill, Shugart, Booth).

Aquatic Secondary Production: Benthos (Koonce, Peterson, Perrotte, Park, Bloomfield, Sterling, Kitchell, O'Neill, Shugart, Booth); Zooplankton populations (McNaught, LaRow, Bloomfield, O'Neill, Shugart, Booth); Zooplankton vertical migration (Bloomfield, McNaught); Fish biomass (Kitchell, Koonce, O'Neill, Magnuson, Shugart, Booth).

Aquatic Decomposition : Decomposition (L. Clesceri, Bloomfield, O'Neill, Shugart, Booth).

Aquatic Nutrients: Nitrogen (Dettmann); Phosphorus (Koonce, Harris, Armstrong); Aquatic nutrients (Park, Koonce, O'Neill, Bloomfield, Dettman, Shugart, Mankin, Goldstein)

Terrestrial Primary Production. Research in this area has resulted in improved measurement techniques (Dinger, 1971a, Strain *et al*., 1971), data on forest canopies (Dinger, 1971b, Mulroy *et al*., 1971), and greater knowledge on the effects of radiation (Strain *et al*., 1971), temperature (Mulroy, *et al*., 1971), moisture and soil nitrogen stress (Richardson, 1971a, b), and leaf temperature and light intensity (Gresham and Wuenscher, 1971) on primary production. A number of models have also resulted, including some which will estimate stand biomass (Ralston and Chapman, 1971; Higginbotham, 1971), standing crop and net stand production (Harris *et al*., 1971) and one that compares forest and agricultural productivity (Whigham *et al*. 1971).

A model of the growth dynamics of loblolly pine was developed (Murphy, 1971a), and the primary production responses of a natural hardwood forest and a managed loblolly pine plantation were compared (Kinerson, Dinger, and Harris, 1972). A photosynthesis model was also developed (Goldstein and Mankin, 1971) as was a carbon budget for a hardwood forest ecosystem (Reichle *et al*., 1972). The latter indicated that net ecosystem production was highly dependent on heterotrophic activity, particularly decomposer metabolism. Numerous models of forest growth also appear in Murphy *et al*. (1972).

In order to determine the level of simplification which would be acceptable for a model of forest stand energy transport and photosynthesis, three models of varying amounts of sophistication were explored (Sinclair, Knoerr, and Murphy, 1972). All predicted the amount of photosynthesis and vegetative water loss. The first was a complete micrometer logical model that calculated the vertical profiles of various environmental parameters. The second made the assumption of infinite eddy diffusivity values (i.e., except for radiation, there were no vertical gradients for environmental parameters). The third assumed that the entire canopy was a single layer of leaves. The results of the first two models were close enough to assume that the assumption of the second model was acceptable. Results also showed the third model was not acceptable.

A canopy model for natural deciduous forest (O'Neill et al., 1972) assumes no vertical gradients of environmental parameters except light and expresses photosynthesis as a function of plant water potential, environmental temperature, and physiological time (an integral response of one or more environmental variables over time).

The daily course of forest metabolism (net photosynthetic assimilation and CO_2 evolution in respiration) and the major environmental controls were measured for a Liriodendron forest (Sollins et al., 1973). This provided a data base for a series of models which predict variation in forest metabolism and make possible the assessment of impacts of change in the limiting factors.

A deterministic model of forest biomass production and turnover for a watershed (Goldstein and Harris, 1972) simulates autotroph behavior in mineral cycling analysis. This model divides a forest into tree diameter classes. Four density-dependent processes affect biomass (intrinsic growth, transfer among size classes, death and ingrowth). Growth is limited by maximum equilibrium biomass. Mortality increases as biomass density approaches the biomass carrying capacity, which the rates of other processes decrease. The ingrowth rate of a tree size class is proportional to biomass of larger trees at some preceding time.

Studies were also made on root production (Harris, Henderson and Todd, 1972; Cox, 1972) and on a comparison of urban and natural forest production (Lawson, Cottam, and Louchs, 1972). The results of the latter showed natural forest production = $812 g/m^2/yr$ and urban, $775 g/m^2/yr$. Carbon flow and productivity are further analyzed by Harris et al. (in press).

Terrestrial Secondary Production was also investigated with emphasis on standing crop of each component (state variable), biomass turnover rates, and energy utilization at each trophic level. The total energy flow and the partitioning of energy into respiration, production, waste products, and mortality were calculated.

In addition to the description of the productivity of the food chains, studies in the deciduous forest concentrated on the regulatory function of animals in the ecosystem. Apparently, animals (chiefly insects) consume only 5% of the annual production of plants, while soil-litter food chains process about 20-25% of the materials reaching them. The most important decomposer group is the fungi and bacteria which have a dominant role in mineralizing and holding nutrients during transfer from detritus back to producer organisms. The role of microorganisms in decomposition in the deciduous forest was investigated by Ausmus and Witkamp (1973). A dynamic model of insect grazing in a forest canopy was devised by Goldstein and Hook (1972).

This canopy grazing model was developed and implemented to determine insect consumption as a function of leaf generation and time.

$$\bar{c}_j(t) = \frac{dH_j(t)}{dt} + \frac{dG_j(t)}{dt} \cdot \frac{1}{G_j(t)} \cdot H_j(t)$$

where $\bar{c}_j(t)$ = mean consumption rate for generation j at time t,
$H_j(t)$ = mean leaf hole area for generation j at time t,
$G_j(t)$ = mean gross leaf area for generation j at time t.

To obtain continuous estimates of gross leaf area and leaf hole area, field measurements were fitted to the nonlinear function

$$y = \alpha + (\beta - \alpha) e^{-\lambda t}$$

where $y = G_j$ or H_j, α = maximum observed area, β = minimum observed area and λ = growth rate parameter.

Net leaf area was determined for each generation through time from $N_j(t) = G_j(t) - H_j(t)$

These estimates were used to determine cumulative percent consumption for each generation from

$$K_j(t) = \frac{\int_0^t \bar{c}_j(t)\,dt \cdot 100}{N_j(t) + \int_0^t \bar{c}_j(t)dt}$$

Total canopy consumption through time was estimated from

$$T(t) = [\Sigma_j r_j \bar{N}_j K_j] / \Sigma_j r_j \bar{N}_j$$

where r_j = ratio of the number of leaves from a sample in generation j to the total number of leaves, and $\bar{N}_j$ = mean net leaf area of generation j at time t.

Results of this analysis for a tulip poplar (Liriodendron tulipifera) canopy insect population show total insect consumption of canopy foliage to be about 2.51% of the available leaf area. Estimation of insect consumption by a single end-of-season observation results in an estimate of three times the actual value. However, this 2.51% consumption results in a 7.28% loss of photosynthetic surface by September 20.

Terrestrial Decomposition

The rate of decomposition for hardwood and coniferous litter were measured at Coweeta and at Oak Ridge. Liriodendron has a halftime of 7.35 years when calculated using the lignin content (exponential decay rate (K) = 2.078 - (0.097 X lignin content)). CO_2 evolution can be related to litter temperature when Y = $mgCO_2/day/m^2$, x = temperature in °C, a = 696, b_1 = 429, and b_2 = 29.33; $Y = a + b_2x + b_2x^2$. Similarly, ATP content of soil biota has been related to CO_2 evolution and ratios of C/N, C/P, C/S, moisture, and weight of substrate (Ausmus and Edwards, 1972). A seven component trophic model of decomposer activity as affected by litter input, temperature, and moisture was developed for a Liriodendron stand. Coupled to this trophic model are pools and fluxes of Na, Ca, K, P, Mg, C, N, and S (McBrayer, 1971). A 22 compartment model for organic matter transfers in the Liriodendron forest (Sollins, 1971) is constantly being revised and incorporates the effects of substrate components with different rates of decomposition on mineral transfer. Recent progress in this area also appears in Gist (1971) and O'Neill (1972).

Aquatic Primary Productivity

Intensive modeling has been accomplished in this area (Hasler and Koonce, 1971; Loucks, MacCormick, and Dettmann, 1971; Magnuson and Kitchell, 1971; Park and Wilkinson, 1971a, b).

Studies of productivity of aquatic systems in the deciduous forest focused on algae and flowering plants. In order to incorporate the results of extensive field and laboratory work on the photosynthesis, respiration, and growth of a submergent macrophyte which dominates the littoral zone of many lakes in the eastern U.S., a mathematical model for the growth of this species (Myriophyllum) was developed by investigators at Lake Wingra, Wisconsin (Titus et al., 1972). This model describes the physiological processes of Myriophyllum in 10 depth classes in the water column. The environmental variables, light intensity, temperature, and carbon availability, are taken into account at each depth. The results were expressed as standing crop at each depth with the sum corresponding to the data on total biomass.

A mathematical model of phytoplankton growth and nutrient uptake was also developed and tested (Koonce and Hasler, 1972). By providing a means of simulating algae replacement dynamics throughout the year, this model may be useful in analyzing different strategies of nutrient control which supress noxious blooms.

Aquatic Secondary Production

Secondary production studies of aquatic systems were undertaken at Lake George, New York. This work indicates that Zooplankters are of little importance in the control of phytoplankton in oligotrophic lakes (lakes with a small nutrient pool) and in fact rarely utilize a significant portion of the theoretical carrying capacity (K) (McNaught et al., 1972. They do have great influence on aquatic nutrient cycles through remineralization of certain nutrients and may account for the high fluxes necessary for N and P to cycle through the system rapidly enough for the productivity needs of such lakes.

A predator-prey biomass model has been developed based on equations describing feeding, growth, respiration, excretion, gamete production, and predatory and nonpredatory mortalities upon temperature, size structure of fish population and various density-dependent interactions and has been used to simulate standing crop (biomass) of bluegills.

The processes may be expressed as functions for nitrogen, phosphorus, and/or energy as follows:

$$C = \Delta B + F + U + R + G$$

where:

D = Food Intake
ΔB = Growth
F = Egestion
U = Excretion
R = Metabolism
G = Reproduction

Food Intake

The simple relationship

$$D = K \quad A$$

where

D = the amount of food consumed per unit of time
K = a coefficient for turnover rate
A = the average amount of food in the stomach during the time period

provides a direct means of analysing food consumption when

$D_{max} = K \, A_{max}$
D_{max} = maximum aily food consumption
K = turnover coefficient
A_{max} = maximum tomach content

The data can be taken from McComish's (1970) long-term ad libitum feeding experiments (21.°C and photoperiod (12L:12D)) using total weight of chironomids consumed per day and weight of fish. Values for D_{max} (.027 - 868 g dry food per day) were regressed against average fish weiht (wet wt, 1.07 - 132.74 g; n = 36) and produced the equatin

$$D_{max} = .0008 \, (\text{fish wt})^{.61521}, \; r = .97$$

A_{max} was determined by wighing the stomach content of satiated bluegill giving maximum tomach contents of .0040 - .2951 g dry wt of live fish weighing .4 - 55.35 g; n = 36. The regression equation was

$$A_{max} = .00736 \text{ (fish wt)}^{.84911}, \; r = .89$$

At 21.0°C

$$K = \frac{D_{max}}{A_{max}}$$

$$= \frac{.04108 \text{ (fish wt)}^{.61521}}{.00736 \text{ (fish wt)}^{.84911}}$$

$$\text{thus, } K = 5.58152 \text{ (fish wt)}^{-.23390}$$

The negative exponent substantiates the hypothesis. Previous applications (Kitchell, 1970) indicate an accurate prediction of the maximum rate of food consumption and should be equally accurate at lower levels. Growth rates, particularly of species with indeterminate size such as fish, are relatively good barometers of changes in the ecosystem (Hall *et al.*, 1970). Growth of size of fish or of size of seals (Gerking, 1966) manifest the difference between intake and the sum of all output processes:

$$\frac{\Delta B}{\Delta t} = D - (F + U + R + G)$$

Assimilation efficiences ($\frac{D-F}{D}$ x 100) are used to express egestion rates.

Applicable assimilation efficiency of phosphorus by Lake Wingra fish species are not available. Energy assimilation is generally given as 80-85% (Mann, 1967) and nitrogen assimilation as 90-100%. Egestion rates are estimated by considering some knowledge of food quality (DOM component):

$$F = K_2C$$

where

F = rate of egestion

K_2 = coefficient for a food type (% IM of dry wt)

C = rate of food intake

Excreted carbon, nitrogen and phosphorus comprise an important source of nutrient regeneration to the water column. Carbon excretion (large as CO_2) is considered as an output of the metabolic process.

While phosphorus excretion has received little ecological attention (Pomeroy and Kuenzler, 1969), the physiological literature (Hoar and Randall, 1969) is helpful. Excretory rates are

$$U = K + c_1 X_1 + c_2 X_2 + c_3 X_3$$

where

U = log excretion rate

K = constant

X_1 = log fish weight

X_2 = feeding level

X_3 = temperature

c_1, c_2, c_3 = regression coefficients

Basal metabolic level is approximated by $c_1 X_1$, while $c_2 X_2$ is associated with feeding and $c_3 X_3$ with thermal conditions. Generally c_1 is 0.80 for metabolic studies (Paloheimo and Dickie, 1966; Kerr, 1971), but Savitz (1969) used 0.93-0.99 for excretion of nitrogen by bluegills. Seasonal changes in gonad weight and composition provide a measure of the fraction of assimilated energy and nutrients expended in gamete production (LeCren, 1962).

The preceding model was designed to simulate growth of top consumers in lakes (fish) and organized the biological components into three levels: mass balance, equation of energy and nutrient budgets at the organism level, interactions between individuals at population level, and interactions between predator prey populations across trophic levels. Also included were terms for the influence of the real conditions, site structure of populations, and biomass exchange across trophic levels. The model was validated by comparing simulation output and experimental results on a study of bluegill (Kitchell et al., 1974). A recent model by Smith et al. (1975) is also of interest.

Aquatic Decomposition and Mineral Cycling

Productivity of the decomposers was measured in two ways in the EDFB studies: (1) maximum growth rate of microbiota and associated substrate turnover rates, (2) microbiological growth rates measured by chemostat techniques and associated substrate turnover. Heterotrophic microbiological activity in the freshwater ecosystem was studied with a twenty-two compartment decomposition process model of the carbon transfers. The model includes anaerobic and aerobic interactions for the water column and surface sediments, anaerobic interactions in deep sediments, and thermal stratification between transfers in the epilimnion, in the hypolimnion, or both. Organic carbon has been divided to require or not to require prior hydrolysis before cellular assimilation. The system is assumed to be reduced-carbon limited; mixing of dissolved carbon is not considered and deep sediments serve as a permanent carbon sink.

Microbial growth accounts for each transfer and implementation, or transport. In pure culture

$$dx/dt = \mu x - Dx$$

or growth rate = (growth rate constant) (concentration of cells)
- (dilution rate constant) (concentration of cells)

For mixed culture

$$dx/dt = \mu x - \rho x$$

where ρ is a removal rate constant.

If changes in population type are minimal, microbial biomass is estimated by ATP concentration. Steady state, biomass measurements do not indicate turnover of organic material. The use of a chemostat approximates the natural open system and permits measurement of the growth rate of a mixed population at steady state from a knowledge of the volume (v) and flow rate (f). The growth rate is u = f/v and the doubling time is v/f. C, N, and P turnover is obtained by chemical analysis of influent and effluent.

The yield coefficient (grams cells/grams substrate) is required to convert values for growth rate into substrate turnover numbers. Nitrogen and phosphorus turnover can be determined by the analysis of influent and effluent of a chemostat and the soluble and particulate CO_2 and CH_4 by monitoring the off-gas. Concern about population changes during chemostat operation can be minimized by operating close to the dilution rate that produces the *in situ* growth rate. A lake water column nitrogen model was devised by Dettmann (1973) and a lake water balance simulation model by Dettmann and Huff (1972).

Physical and Chemical Processes

Biological processes, such as productivity, are limited by the availability of nutrients and by certain physical properties of the environment. A number of IBP studies involved estimating parameters of limiting physical processes through physical and chemical studies of reaction rates, flows, and transformations. Process equations showing the relation of the estimated parameters to system components are basic to ecosystems analysis.

Meteorological or climatological parameters -- In the EDFB, studies of meteorological parameters were linked with primary production research. Atmospheric processes affect energy exchange, $CO_2 + O_2$ transport and the temperature; therefore, measurement of solar and net radiation, wind speed, air temperature and humidity were made in connection with studies of photosynthesis, respiration, and transpiration. Models of leaf and canopy energy balance were developed and tested (Murphy and Knoerr, 1972), and the relation of the physical measurements and process models to CO_2 concentration, photosynthesis, and water loss were studied (Murphy et al., 1972).

A more simplified meteorological model was also tested (Sinclair, Knoerr and Murphy, 1972). This model can be implemented with a limited number of atmospheric and vegetation parameters. It agrees within 10% of the estimates made by the more intensive model and may provide the basis for a fairly wide application of this model in estimating the effects of forest ecosystem perturbation and management.

Other advances in this area include a microclimate water balance model (Goldstein and Mankin, 1972) and a computer-based data acquisition system (Koonce and Hasler, 1972).

Hydrology.- Within the Eastern Deciduous Forest Biome, the watershed has been identified as the fundamental land unit for defining and modeling ecosystems. Central to an ecosystem model at this level of resolution are the hydrological processes that determine water fluxes and storages within the drainage basin (EDFB - IBP -73-5). Water is essential not only to every organism in the ecosystem but to every biological process: productivity, mineral cycling and decomposition (Huff, 1975). Parameters and quantitative models describing moisture supply and movement are fundamental to an understanding of ecosystems. Surface and groundwater hydrologic studies involve measurements of precipitation, temperature, potential evaporation, geology, soils, vegetation, interruption, infiltration, soil moisture storage, surface flow, and groundwater losses. At several EDFB sites, basic hydrological modeling was linked with root uptake of water, transpiration and stomatal control. The resultant model is capable of predicting changes in stream flow as a function of vegetation characteristics (i.e , effect of changes in vegetation cover on hydrology) (sites involved -- Oak Ridge, Tennessee; Coweeta, North Carolina; Lake Wingra, Wisconsin; Lake George, New York).

Modeling activities in this area have resulted in a biome watershed simulation model (Huff, 1971a, b), hydrologic simulation of lake ecosystems, and a model of lake circulation and material transport (Hoopes, Monkmeyer, and Green, 1971).

The hydrologic simulation program (CHANSIM) was improved and a program modification (DAMRUN) was developed that included hydraulic effects of lakes or other impoundments located within a drainage basin (Jacques and Huff, 1972a; Ivanson, Jacques, and Huff, 1972).

Other advances in hydrological modeling relate to data collection. Cullen and Huff (1972) give a description of the land use categories necessary for parameterizing subbasins for simulations. Soil mapping and characterization studies appear in Huddleston (1972) and in Huddleston, Luxmore, and Hole (1972).

Soil-Plant-Water Relations.- The water present in the rooting zone influences stomatal opening, CO_2 uptake, and, subsequently, primary productivity. Forest biome simulation models allowed the investigation of variation in soil water stress as a function of physical properties and geographic location.

Terrestrial nutrient cycling.- Research in nutrient cycling concentrated on two questions: What are the turnover rates as functions of time, space, and environmental stress? What are the sizes of the nutrient pools (especially N and P)?

In the deciduous forest the movement of the nutrient elements N, P, K, Na, Ca, and Mg into, within, and out of the terrestrial ecosystem were characterized. Substrate geology was found to have a significant impact on nutrient input and output.

The pool size and cycling rates of individual system components were assessed. Though absolute amounts of N, P, and K vary widely in the vegetation, their distribution in the major vegetation pools is similar (65% of each in woody material, 22% in roots, 13% in foliage). The vegetation as a whole stores 11% of the N, 4% of the P, and less than 1% of the K found in the ecosystem. The surface litter layer holds most of the nutrients found in the organic horizon but the mineral soil horizon is a much more important nutrient pool.

Root mortality was shown to be the dominant process in recycling N, P, and K from the vegetation pool to the soil. Litter fall was next in importance for N and P, and foliage leaching was next for K. The limiting factor in decomposition is the availability of organic carbon.

The N cycle of the deciduous forest is effectively closed by incorporation of N in soil organic materials available for subsequent plant uptake (Henderson and Harris, in press).

At Oak Ridge a study of the effects of N and P fertilization on litter decomposition nutrients, and mineralization showed that nitrogen addition enhances decomposition whereas phosphorus fertilization has an inhibiting effect.

A mineral cycling model was developed by Gist (1971) and other work on terrestrial nutrient cycling was published by Boyle, Keeney, and Northup (1971) and by Endleman (1971).

Aquatic Nutrient Cycling.- N and P are two most important nutrients in lake ecosystems. Research on the cycling of these elements encompassed field monitoring of N and P, laboratory process studies, and development of models for Lake Wingra in Wisconsin and Lake George in New York.

Watershed hydrologic models made it possible to couple terrestrial hydrologic studies with studies of adjacent lake circulation models. The result was a model which predicted the fate of materials transported from terrestrial to aquatic ecosystems. One such circulation model depicted the resuspension or retention of nutrients and soil particles based on wind-shear inputs and lake morphometry (Hoopes et al., 1972).

Other studies emphasized nutrient inputs and losses from identifiable sources and sinks. The study of Lake George indicates sewage is responsible for only 11% of the N but for as much as 66% of the P entering the lake (Aulenbach and Clesceri, 1972).

Detailed process models were developed for N and P cycling in Lake Wingra. Phosphorus pool size, rates of turnover of its various forms, and kinetcs of uptake and release by organisms were studied as were phosphorus exchange between water and sediments. Inputs were monitored and a model of phosphorus cycling was developed which described phosphorus transport through food webs via biota simulation models, regeneration of phosphorus from sediments, and phosphorus transport to the lake from terrestrial and geologic sources. A similar study was made of nitrogen.

Another study of nitrogen investigated the role of terrestrial and atmospheric inputs in the control of seasonal variation of total nitrogen in the water column. This model assumed that the nitrogen content of lake water can be determined by abiotic processes (atmospheric deposition and hydrologic transport) and biological processes (nitrogen fixation, denitrification, remineralization, sedimentation). Two coupled first-order differential equations describe the nitrogen pool in the water body and the labile nitrogen in the suspended detritus (Dettman, 1973).

Simulation outputs for this model indicate that the system is most sensitive to sedimentation and regeneration of nitrogen from the sediments (Dettman, 1973).

ECOSYSTEM LEVEL MODELS

The analysis-of-ecosystems programs of the IBP emphasized research in the basic biological, physical and chemical process of ecosystems for the first two to four years in order to advance the understanding of these processes to the point that modeling and analysis of entire ecosystems could be attempted. Characterization of the entire ecosystem and validation of these ecosystem models was the primary concern of the later years of IBP.

The ecosystem-level models were to contain simplifications and assumptions appropriate to a particular problem and were assembled from individual biological, chemical, and physical process models which described the current understanding of subsystems. These models conceptualize the ecosystem as a functional unit with recognizable boundaries and internal homogeneity. The boundaries, of course, are arbitrary and are placed to give the ecosystem a full set of interacting processes and to allow inputs and outputs across the boundaries to be measured easily.

After establishing the boundaries of the ecosystem, a model must identify all the significant components. The abiotic components include the air, land, water (collectively, the abiotic environment), and the biotic components include the producers (plants), consumers (animals) and decomposers (fungi and bacteria). Ideally, the number of components necessary to account for the significant ecosystem processes will be no more than several hundred.

Smith (1970) suggests that the ecosystem might be described by a series of tables specifying the amount of energy or elements or other parameter in each of the components and the inflow and outflow from these components. Another approach might be the construction of a matrix which shows the rates of transfer of energy or elements or other parameter between the components of the ecosystem. The rows of the table represent the losses from a component. The sum of these losses is the total rate of loss to other components. The columns show gains for each component and the column sum yields the total rate of gain from the other components.

With this information, it is possible to write an equation for the rate of change of each parameter for each component. For component i:

$$dx_i/dt = a_i - z_i + (y_{1i} + y_{2i} + \ldots + y_{ni}) - (y_{i1} + y_{i2} + \ldots + y_{ni})$$

This approach lends itself to computer simulation, beginning with all the x_i's at their estimated levels and letting them change through time according to the equation, dx_i/dt.

Obviously, this approach is not adequate as each component will simply change in the same direction at the same rate for the duration of the simulation. A natural ecosystem responds to change with changes in rates. A variable rate expressed as a function of the system is needed. Each transfer rate is a set of functions, an equation, which relates the rate to the factors which govern it. Using these functions, a computer simulation can predict how the system might respond to change (Smith, 1970).

In order to express rates as sets of functions, it is necessary to estimate many parameters other than amounts and rates. Smith specifies an open list of descriptors of each component. These are in addition to the x_i, a_i, z_i, and y_{ij} and like y_{ij} and z_i are sets of functions. Examples of these descriptors are average size and number of individuals in a component and age structure. A set of external input variables (A_i) such as climate and season are also included. With the inflows (a_i), these externally controlled variables influence, but are not influenced by, the systems. The rates y_{ij} and z_i which measure systems processes are functions of the aforementioned amounts and rates.

A complete set of mathematical functions describing the effect of external variables and relationships among internal variables is an ecosystem model. It may be validated by specifying the initial amounts (x_i) and their distribution and a program of input variables (A_i and a_i) which change with time. The results of the simulation are compared to field observations. A "valid" model is one which reasonably simulates actual field observations.

The following is a partial list of developed ecosystem-level models.

Ecosystem Models: Terrestrial ecosystem model (O'Neill, Goldstein, Shugart, Mankin); Energy dynamics (Reichle, Edwards, Harris, Shugart, O'Neill); Nutrients in manipulated ecosystems (Gist, Waide, Site Investigators); Terrestrial nutrient cycling (Henderson, Harris, Shugart, Goldstein, O'Neill, Reichle, Edwards); Carbon flux in forest stands (Sollins); Stand nutrient budget (Wells, Swindell); Watershed vegetation (Goldstein, Harris); Land-water interaction (Dettmann, Huff, Harris); Hydrologic transport model (Huff, Jacques, Goldstein, Mankin, Reeves, Miller); Lake ecosystem analyzer (Park, Bloomfield, Sterling, Kohberger, Wilkinson, O'Neill, Shugart, Booth, Koonce, Nagy); Littoral zone model (Weiler, Adams, Gasith, Koonce, O'Neill).

Subsystem Models: Phytoplankton-zooplankton kinetics (Bloomfield, Kohberger, Hwang, Park); Terrestrial primary production (Murphy, Sinclair, Kinerson, Site Investigators); Stream subsystem (Webster, Woodall, Barr, Elwood); Aquatic biomass (MacCormick, Loucks, Kitchell, Koonce, Weiler).

Applied Models: DDT transport (O'Neill, Burke, Booth); Aleut ecosystem (Hett, O'Neill).

Trophic Interaction Model: De Angelis et al., 1975.

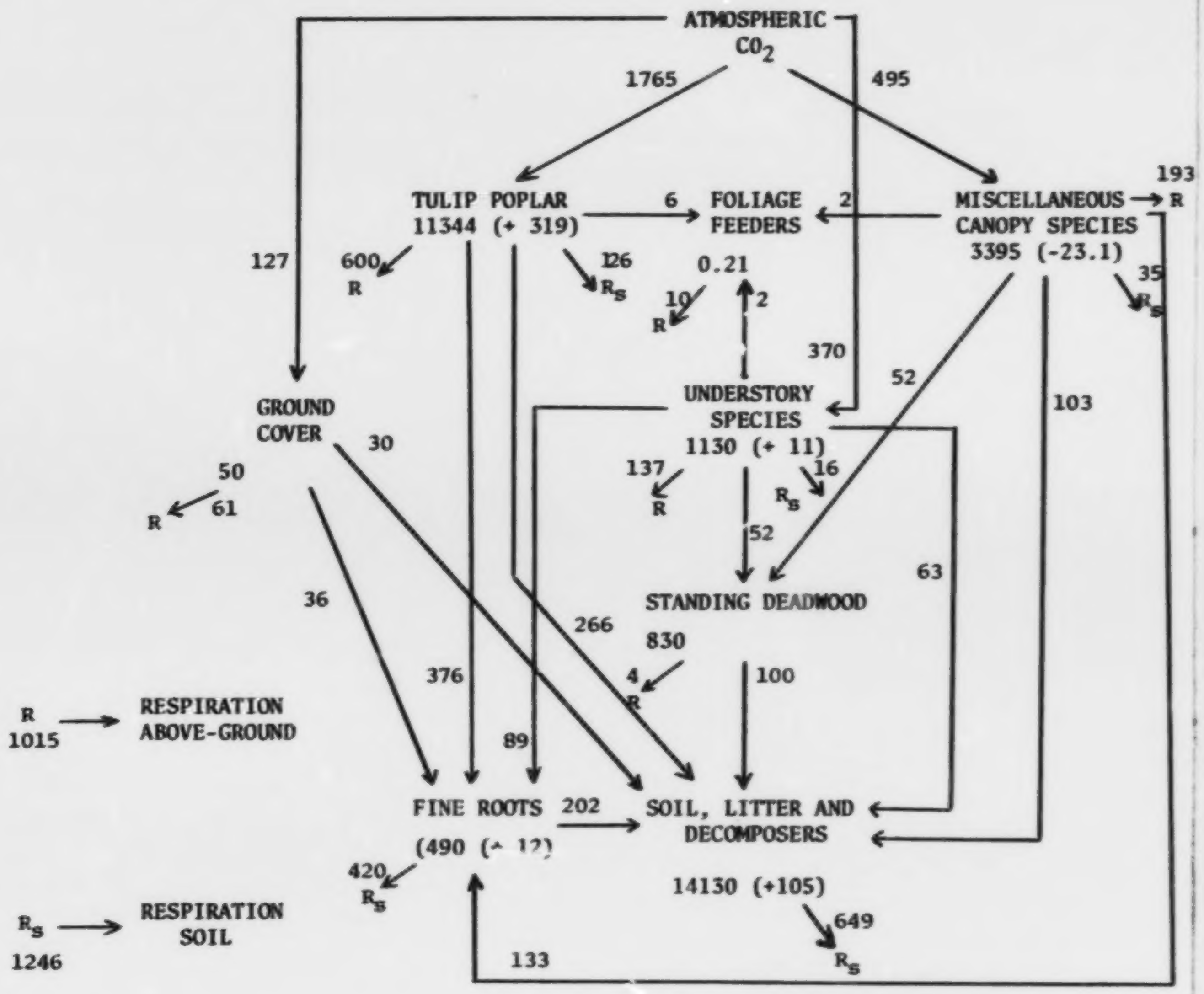

ATMOSPHERIC CO2
1765
495
TULIP POPLAR
11344 (+ 319)
6
FOLIAGE FEEDERS
2
MISCELLANEOUS CANOPY SPECIES
3395 (-23.1)
193
R
127
600
R
126
RS
0.21
10
R
2
35
RS
370
52
103
GROUND COVER
30
UNDERSTORY SPECIES
1130 (+ 11)
50
R
61
137
R
16
RS
52
63
36
STANDING DEADWOOD
266
830
376
4
R
100
R
1015
RESPIRATION ABOVE-GROUND
89
FINE ROOTS
(490 (+ 12)
202
SOIL, LITTER AND DECOMPOSERS
14130 (+105)
420
RS
649
RS
RS
1246
RESPIRATION SOIL
133

Figure 4-1. Forest Ecosystem Biomass Budget.

Compartment values are grams of dry weight per square meter; all transfer and increment values (in parentheses) are g m^{-2} yr^{-1} (Sollins, 1971).

Terrestrial Models of the Eastern Deciduous Forest Biome

Several ecosystem models of the deciduous forest were constructed of sets of process models of nonlinear components (Sollins, 1971). The terrestrial production model included submodels of primary and secondary production, assimilation, and arthropod and microbial decomposition. This model is capable of predicting the response of the system to outside manipulation. Considerable sophistication has been incorporated into the primary production sections of the model, and stress is placed on the roles of the consumer and decomposer organisms. In addition, the model is being modified to incorporate the influence of water availability and nutrient status on primary production (Shugart, et al., 1974).

Additional refinement is anticipated when a primary production submodel (Murphy, 1972) is finalized, linking micrometeorological processes to photosynthesis.

Another model for terrestrial consumer biomass considers physiological, behavioral, and size distribution effects on feeding, excretion, respiration, predation and natural mortality (O'Neill et al., 1972).

$$\frac{dx_j}{dt} = Z_j' \left[\frac{\sum_i W_{ji} \ (1-e_{ji})}{x_j + \sum_i W_{ji}} \right] - \sum Z_k' \left[\frac{x_k W_{kl}(t,S)}{x_k + \sum W_{kl}} \right] - \left[\frac{x_j}{K_j} + 1 \right] \left[Z_j'' + Z_k''' \right]$$

$$Z_j^m = a_j^m \ (t,S) \left[b_j^m(t,S) \frac{K_j - x_j}{K_j} + 1 \right] c_j^m(S) x_j$$

$$W_{ji} = W_{ji}(t,S) x_i$$

where

t is time,

S is a set of environmental factors such as temperature,

x_j is standing crop of consumer group j,

x_i is standing crop of group i, which represents a food supply for consumer group j,

x_k is standing crop of predator group k, which feeds upon consumer group j,

x_l is standing crop of any other consumer group, l, which is also eaten by predator group k,

e_{ji} is the fraction of group i consumed but not assimilated,

k_j is the largest standing crop of group j which can be supported by the environment (carrying capacity),

a_j^m (t, S) is a function which modifies feeding ('), mortality ('') or respiration (''') due to events in the individual consumers annual behavior cycle, e.g., going in or coming out of hibernation,

b_j^m (t, S) is a function which modifies feeding ('), mortality ('') or respiration (''') due to birth and maturation of young. For example, due to allometric relationships,

c_j^m (t, S) is a function which modifies feeding ('), mortality ('') or respiration (''') due to physiological factors, for example, the dependence of rates on temperature,

W_{ji}(t, S) is a function which expresses changes through time in the availability of food source i to consumer j.

A study of the ecological effects of power plant siting was conducted by applying portions of a preliminary regional model. The size and location of a hypothetical power plant were predicted from socioeconomic and land use simulation portions of the total model. A Gaussian plume air diffusion model was used to predict concentrations of SO_2 and fly ash at grid points across the region. Information from ecological literature was used to predict damage to commercial crops. (Figure 4-2.).

While most models emphasize interseasonal dynamics, one simulates primary production over greater time and spatial scales. Regeneration, mortality and other processes affecting tree populations on a total watershed have been incorporated into a model that simulates long-term development of vegetation throughout a heterogeneous forest system (Goldstein and Harris, 1972).

BIOMASS POOLS	Zooplankton B_2	Benthos B_3	Fish 1 B_4	Fish 2 B_5	Sus. Det. B_6	Prm. Sed. B_7	D.O.M. B_8
B_1	C_{12}	C_{13}			D_{16}		U_{18}
B_2		C_{23}	C_{24}	C_{25}	D_{26} F_{26}		U_{28}
B_3				C_{35}	D_{36} F_{36}		U_{38}
B_4				C_{45} RC	D_{46} F_{46}		U_{48}
B_5			BR		D_{56} F_{56}		U_{58}
B_6	C_{62}	C_{63}				S_{67}	V_{68}
B_7							V_{78}
B_8					V_{86}		

Figure 4-2. Biomass Flow Matrix
Read from the left-hand margin to the upper margin (McCormick, et al., 1974). B_1 is Phytoplankton.

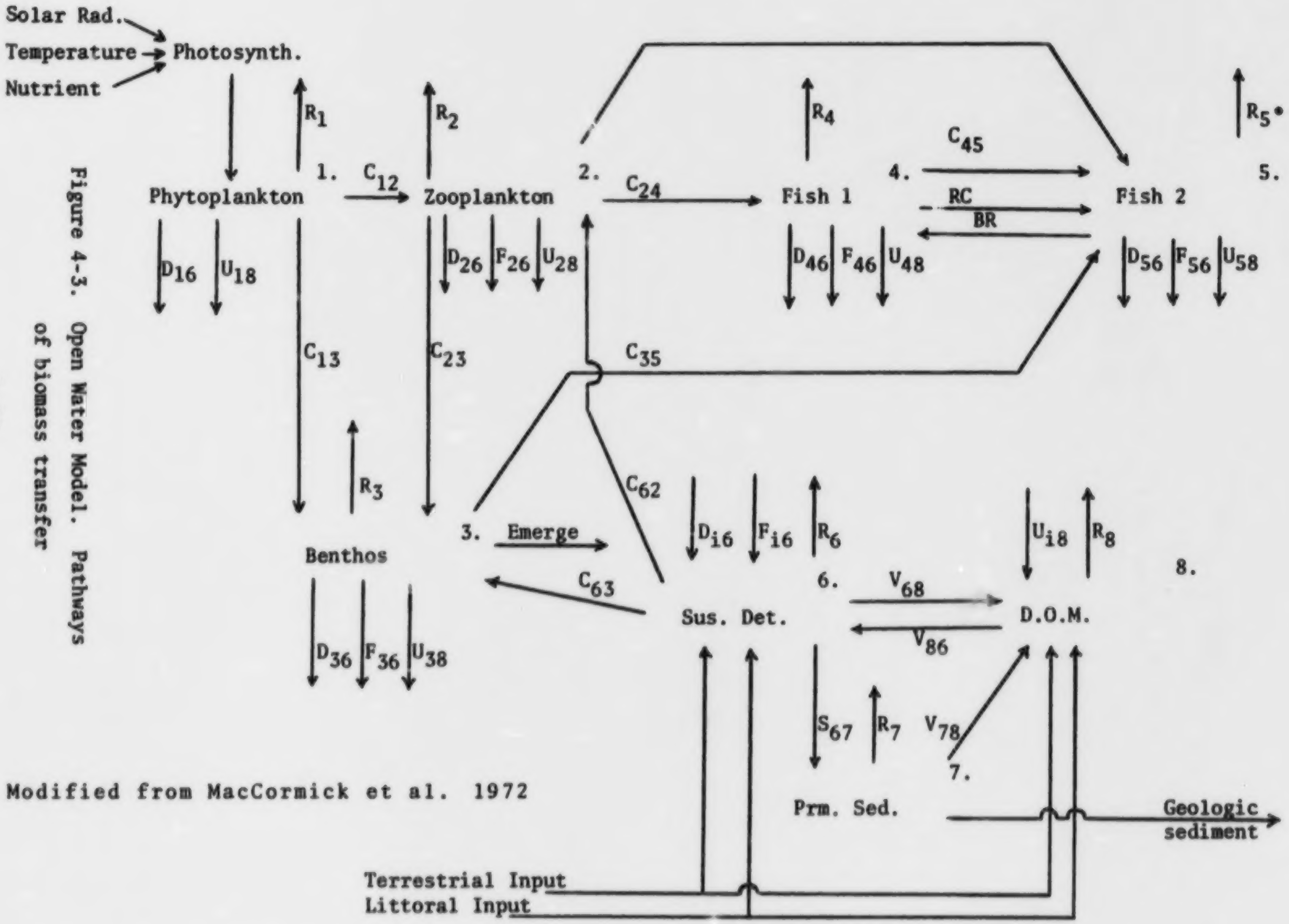

Solar Rad.
Temperature
Nutrient
Photosynth.
R1
R2
R4
R5*
C45
1.
C12
2.
C24
4.
5.
Phytoplankton
Zooplankton
Fish 1
RC
BR
Fish 2
D16
U18
D26
F26
U28
D46
F46
U48
D56
F56
U58
C13
C23
C35
R3
C62
D16
F16
R6
U18
R8
3.
Emerge
Benthos
8.
C63
6.
V68
Sus. Det.
D.O.M.
V86
D36
F36
U38
S67
R7
V78
7.
Prm. Sed.
Geologic sediment
Terrestrial Input
Littoral Input

Figure 4-3. Open Water Model. Pathways of biomass transfer

Modified from MacCormick et al. 1972

Inputs

Photosynthesis
Littoral zone and terrestrial exports

Principal system variables

B_1 Phytoplankton
B_2 Zooplankton
B_3 Benthos
B_4 Fish 1 (up to yearlings)
B_5 Fish 2 (2 yr or older)
B_6 Suspended detritus
B_7 Permanent sediment
B_8 Dissolved organic matter

Outputs

R_i-Respiration (temperature dependent)
Deep geologic sediment

Transfer terms

C_{ij}-Feeding (temperature dependent)
D_{ij}-Mortality (nonpredatory)
F_{ij}-Egestion
U_{ij}-Exudates and excretion
S_{ij}-Sedimentation
V_{ij}-Heterotrophic processes (temperature dependent)

Figure 4-3. (Continued)

From MacCormick *et al*.

Aquatic Models of the Eastern Deciduous Forest Biome

Lake models.- Ecosystem models were also developed for the aquatic systems of Lake Wingra (MacCormick et al., 1972) and Lake George (Park et al., 1972; Park et al., 1975; Scavia et al., 1975)

WINGRA II, a nonlinear model of a pelagic-zone lake drew on advances in process subsystems models, particularly the algae production and secondary production mentioned under Ecosystem submodels - productivity. The table of compartments of WINGRA II shows inputs and outputs, and the transformations are shown on pages 25, 26, and 27. The photosynthesis submodel of Koonce and Hasler (1972) is the primary input to the system, while the principal process components include feeding flux, maintenance loss (respiration), excretion, egestion, mortality (non-predation), decomposition flux, and carbon uptake and loss. Eight diffenential equations describe the rate of change of biomass in the eight compartments of the open water biomass model (phytoplankton, zooplankton, benthos, fish 1, fish 2, suspended detritus, primary sediment, and dissolved organic matter).

The Lake Wingra model has been used to model the response of a lake to nutrient loading from urban sources (Huff et al., 1973). It was also used to stimulate algae biomass in a proposed river impoundment (Dettmann, mimeograph). These studies suggest that algal biomass will be changed little because the nutrient loading is low or is diverted by passing through areas with considerable vegetation.

CLEAN (Comprehensive Lake Ecosystem Analyzer) is a generalized, yet realistic, lake ecosystem model developed in response to the need for large-scale, integrated approaches to the proper management of complex lake ecosystems. Park et al., (1974) documents this model which was developed by a team of aquatic specialists and systems modelers and designed as a diagnostic tool to study the effects of nutrient enrichment and other perturbations on the lake ecosystem. CLEAN was formulated so as to be applicable to both Lake George, New York, and Lake Wingra, Wisconsin, and is presently tested with data from both sites. Thus far, realistic simulations have been obtained and the validity of the model has been established on three bases: (1) three five-year simulations beginning at different levels of biomass ran to the same steady state values; (2) relationships among the trophic level compartments were shown to adhere to ecologic theory; (3) predictions were shown to be reasonably accurate for the planktonic component (Scavia, 1974). CLEAN represents an advance over previous models; individual ecologic processes are represented in greater detail and a broader spectrum of mechanisms involved in lake ecosystem dynamics is included.

The model is actually a collection of submodels, each focusing on a specific component of the system. It is presently formulated as 38 coupled ordinary differential equations each representing one of the most important compartments of the lake ecosystems. Subprogram functions exist for principal physiologic and ecologic processes. Detailed interactions appear on page 30. The driving variables include incident solar radiation, water temperature, nutrient loadings, wind, changes in barometric pressure, and influx of dissolved and particulate organic matter for a terrestrial system. A separate circulation model is now available to be run with CLEAN** (Park et al., 1974)** and a lake water balance submodel is being implemented.

CLEAN employs modular programming and is written in FORTRAN for both UNIVAC and IBM time-sharing systems (p. 30).

River-Model.- Unfortunately, the ecological modeling of aquatic systems other than lakes have not received as much attention. A river model appears in Appendix V-B of *Alternatives for Managing Wastewater in Chicago--South End Lake Michigan Area* (Corps of Engineer, Chicago District). This model, represented schematically on page 31, divides the river or stream into ecologically meaningful reaches. Inflow from upstream, base flow, inputs of treated effluent, untreated storm water, and fresh water from an external source, as well as outflow downstream, are represented.

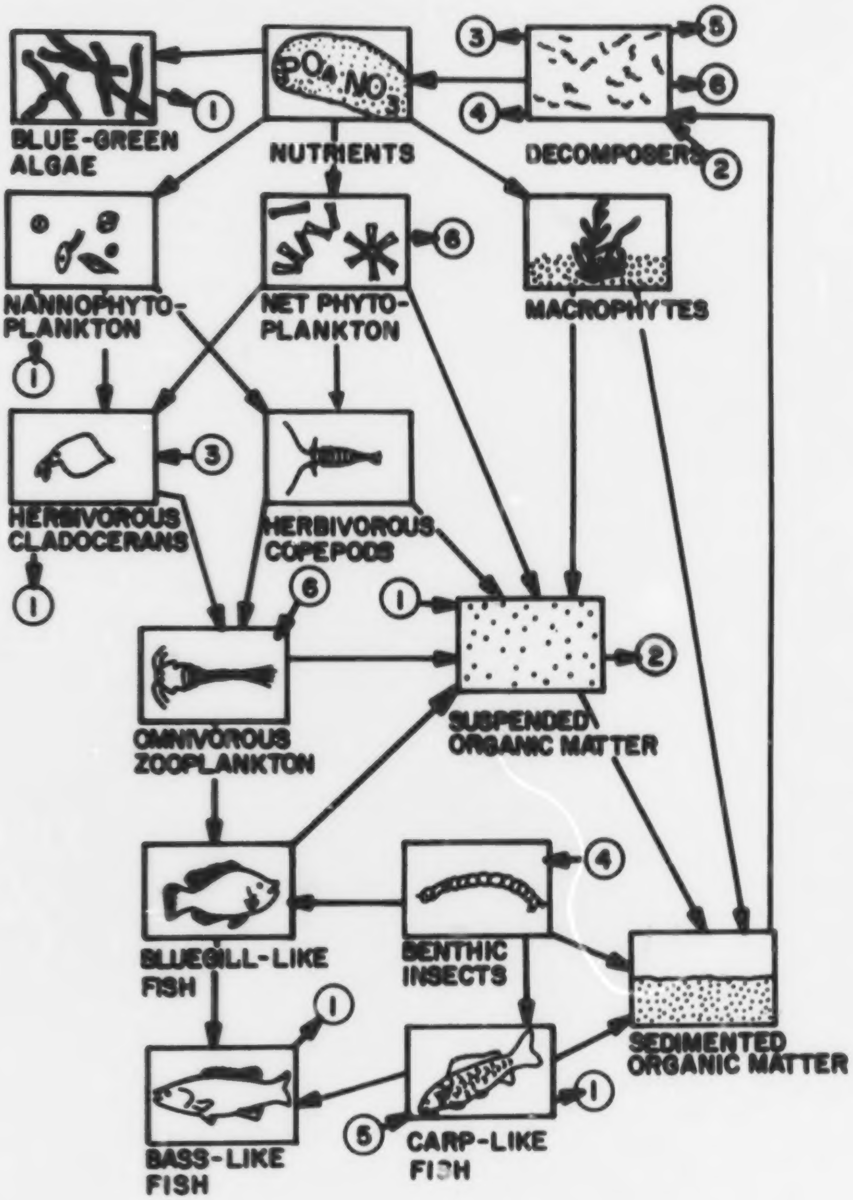
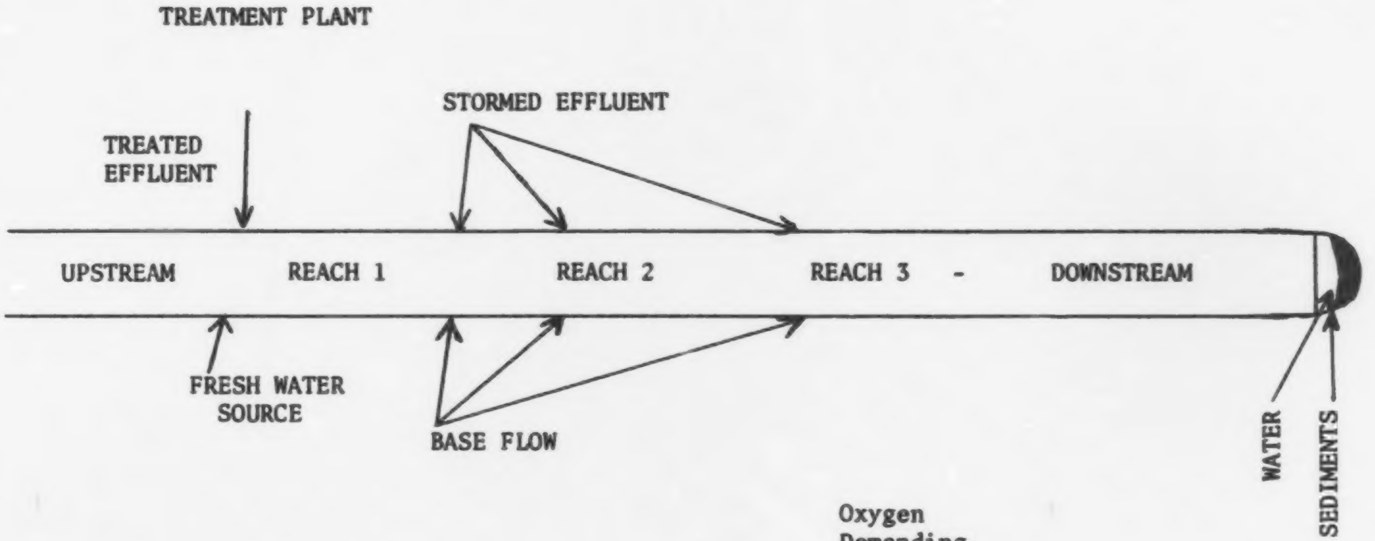

BLUE-GREEN ALGAE
PO4 NO3
NUTRIENTS
DECOMPOSERS
NANNOPHYTO-PLANKTON
NET PHYTO-PLANKTON
MACROPHYTES
HERBIVOROUS CLADOCERANS
HERBIVOROUS COPEPODS
OMNIVOROUS ZOOPLANKTON
SUSPENDED ORGANIC MATTER
BLUEGILL-LIKE FISH
BENTHIC INSECTS
SEDIMENTED ORGANIC MATTER
BASS-LIKE FISH
CARP-LIKE FISH
①
②
③
④
⑤
⑥

Figure 4-4. INTERACTIONS OF CLEAN
Provided by R. A. Park


TREATMENT PLANT
TREATED EFFLUENT
STORMED EFFLUENT
UPSTREAM
REACH 1
REACH 2
REACH 3 - DOWNSTREAM
FRESH WATER SOURCE
BASE FLOW
WATER
SEDIMENTS

Sources	Water			O_2			N			P			Oxygen Demanding Wastes			Biota		
	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Upstream	X			X			X			X			X			X		
Treated Effluent	X			X			X			X			X					
Storm Effluent	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
Base Flow	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
Fresh Water	X			X			X			X			X					
Atmosphere				X	X	X												

Figure 4-5. Stream Model Transfer Matrix

Modified from Dettman, et al., 1970

		Water			O_2			N			P			O_2 Demand			Biota			Sediments			Decomp. Products	Downstream
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3		
Water	Reach 1 (R1)		X																					
	Reach 2 (R2)			X																				
	Reach 3 (R3)																							X
O_2	Reach 1					X											X						X	
	Reach 2						X											X					X	
	Reach 3																		X				X	X
N	Reach 1								X								X							
	Reach 2									X								X						
	Reach 3									X									X					X
P	Reach 1											X					X			X				
	Reach 2												X					X			X			
	Reach 3																		X			X		X
Oxygen Demanding Wastes	Reach 1							X			X				X		X						X	
	Reach 2								X			X				X		X					X	
	Reach 3									X			X						X				X	X
Biota	Reach 1				X									X				X						
	Reach 2					X									X				X					
	Reach 3						X									X								X
Sediments	Reach 1										X			X									X	
	Reach 2											X			X								X	
	Reach 3												X			X							X	

Figure 4-6. System Matrix for River (From Dettman et al., 1970)

In addition to inputs and outputs, an adequate model must describe processes occurring within the stream-river, such as aeration, sediment-water interchange, plant production and death, and downstream transport. Without these processes the model could not predict accurately downstream nutrient and oxygen levels.

The basic structure of this stream-river model can be summarized in transfer matrices (p. 32). The rows represents sources of water, oxygen, nitrogen, phosphorus, biota and oxygen-demanding wastes and the water in reaches 1, 2, and 3. The rows labeled "O_2," "N," "P," "biot," and "oxygen-demanding wastes" represent these materials in the three reaches, and the "sediments" rows refer to sediments beneath the reaches. The column labels are similar with the addition of two sinks, labeled "decomposition products" and "flow downstream,"

The "X's" in the matrix represent potential transfers of exchanges. An 'X' in row 1, column 1, represents the flow of water from upstream into reach 1. An 'X' in row 13, column 16, represents the uptake of nitrogen from water in reach 1 by biota.

That matrix which deals directly with stream variables (water, etc., in reach 1, 2, 3) may be called the system matrix, and the entire matrix, including inputs and outputs, the expanded matrix. Then a simple model dealing only with inputs, outputs, and stream transport involves only transfers represented in the input rows and output columns of the expanded matrix and the square 3 x 3 submatrices on the main diagonal of the system matrix. On the other hand, transfers such as biotic uptake and sediment-water interchange, involve only those processes represented in submatrices off the main diagonal of the system matrix. These may be ignored in simple water quality models but must be considered when water quality improvement by biological activity is considered.

This matrix may be a useful tool in the assessment of water quality if the "X"s are replaced by measurements or good estimates of transfer rates.

Estuary Model.- A carbon flux model for a coastal marsh ecosystem (Wiegert et al., 1974) is comprised of 14 state variables or compartments (7 biotic, 7 abiotic). The compartments of the model can be connected with flow pathways and listed sequentially by donor and recipient.

There are two basic types of mathematical representation of carbon flux. Transfers to the nonliving (abiotic) compartments are usually represented by linear, donor-determined, donor-controlled equations (carbon flux between the two compartments is equal to the product of a specific rate of transfer and the standing crop of the donor).

Transfers into a living (biotic) component are usually represented by a nonlinear, discontinuous, recipient-determined but donor-and recipient-controlled equation. In this case, carbon flux is a complicated function of the specific rate of carbon flux, standing crop of recipient, sum of all specific rates of loss from recipient, and vegetation feedback factors.

The computer program for this model is available from the senior author.

Simulations were run on the marsh as a closed and as an open system. The model was also subjected to sensitivity analysis.

MODELING LARGE SCALE SYSTEMS

A landscape consists of many ecosystems, and a unit of political decision-making consists of many landscapes. Studies over large areas require that ecosystem-level models be combined in an hierarchical fashion into a landscape-level model. Such landscape-level models may have ecological, as well as political, meaning as in the case of watersheds and air basins.

The first work addressing ecosystem processes at the landscape level involved characterization of ecosystem types and the changes from one type to another (US participation in the IBP, 1974). Some of these changes were the result of natural processes (succession) while others were a result of human disturbance.

The total primary production for several states was estimated through the use of data on crop yield and forest growth and by analytical techniques reducing such data to total biomass (one example Stearns et al., 1971).

The geographical distribution of production within each state was investigated in relation to patterns of large scale climatic and geologic variations. Production estimates of certain categories omitted in the earlier estimates (suburban land, wetland, rights of way) improved earlier total estimates.

Computer-drawn maps of primary production for the U.S. were made possible by studies of climatic parameters (evapotranspiration) and biomass production (Lieth and Box, 1972).

A regional model of land use change (Hett, 1971) for five counties in Tennessee was constructed from a series of aerial photographs taken from 1939-1964. Each major cover type in the region is a state variable, and the model uses differential equations to predict change from one land type to another.

This land use model has been extended by succession models which incorporate processes on a large scale. A model for the eastern deciduous forest describes succession from one type of forest to another as a result of intrinsic species replacement (natural succession) and disturbance by man. This constant-coefficient, linear compartmental model simulates changes through time in the areal extent of major forest types in Michigan in the absence of perturbations (Shugart et al., 1972). Each compartment represents forest type. (Fig. on p. 36). Within each compartment or module, three submodules correspond to seedling-sapling, pole timber, and saw timber size classes. Data for the model were obtained from the ecological literature and the U. S. Forest Service. The linkages among compartments represent the intrinsic replacement patterns of these forest types. The equilibrium print of the model simulation provided an estimate of the potential composition of the vegetation of the region and served as a reference point from which to examine the role of natural and man-induced disturbances and how they affect the extent and composition of forests in the region.

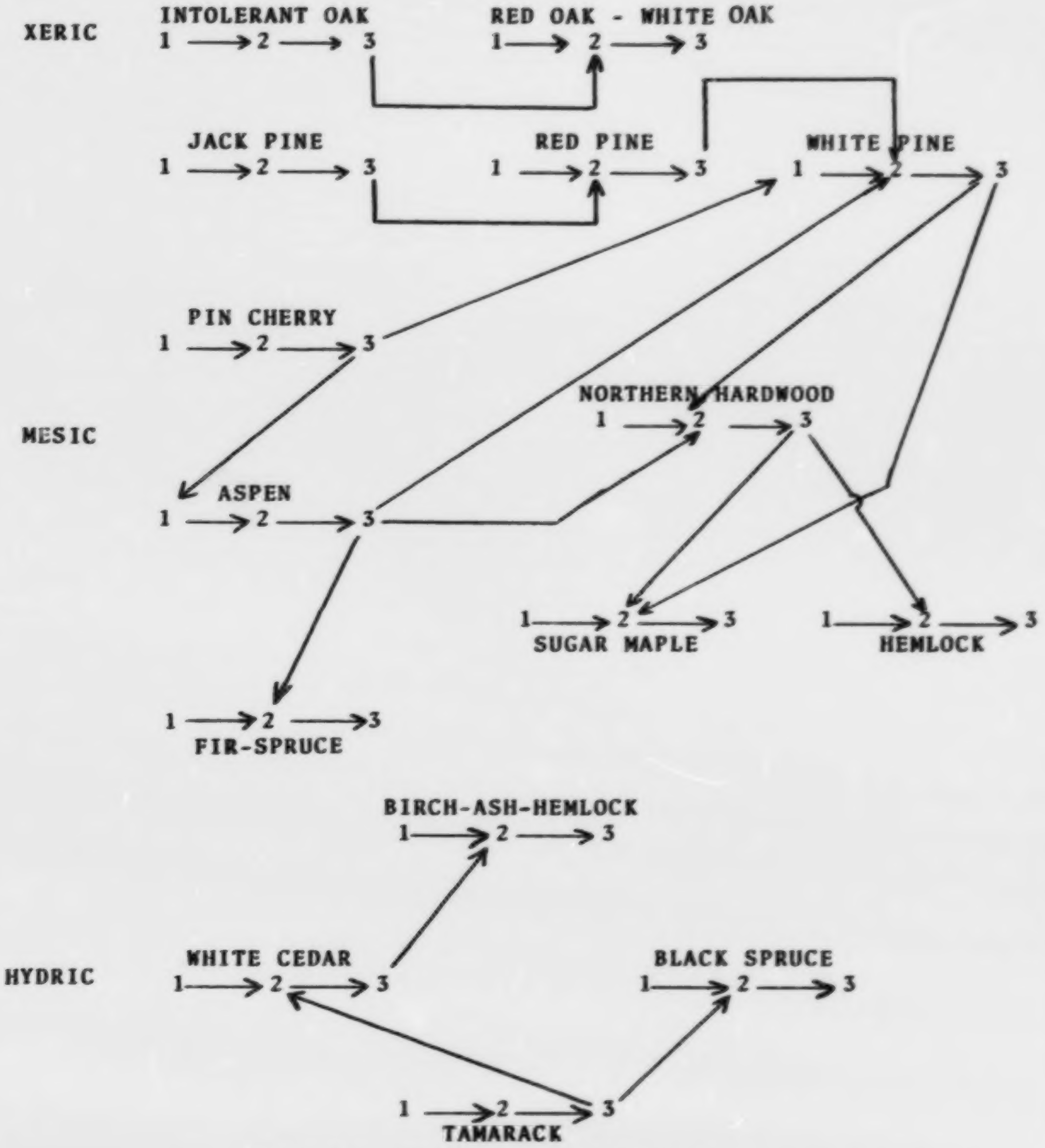

XERIC
INTOLERANT OAK
1 2 3
RED OAK - WHITE OAK
1 2 3
JACK PINE
1 2 3
RED PINE
1 2 3
WHITE PINE
1 2 3
PIN CHERRY
1 2 3
MESIC
NORTHERN HARDWOOD
1 2 3
ASPEN
1 2 3
1 2 3
SUGAR MAPLE
1 2 3
HEMLOCK
1 2 3
FIR-SPRUCE
BIRCH-ASH-HEMLOCK
1 2 3
HYDRIC
WHITE CEDAR
1 2 3
BLACK SPRUCE
1 2 3
1 2 3
TAMARACK

Figure 4-7. Regional Succession Model

Dominant tree species are identified: 1 = seedling-sapling, 2 = poletimber, 3 = sawtimber. Arrows represent transfers of acreages of land from one forest type to another. Modified from Shugart et al. 1972.

This model has been tested in the Great Lakes Region (Shugart et al., 1973) and in the Piedmont region of the southeastern U.S. (Johnson and Sharpe).

Recently, Carlisle of the Rensselaer Fresh Water Institute at Lake George has proposed to aggregate Hett's land use model and Shugart's succession model into one model which would simulate the effects of urbanization upon the Lake George Drainage Basin. His objective is to establish a correlation matrix between land use types and independent variables other than time. Specifically, this will involve the determination of empirical relationships between transportation factors and agricultural and natural areas. Such a study may improve current understanding of land use change and result in a model with the potential to predict the effects of public intrastructure investments which accelerate urbanization.

Terrestrial trophic models and aquatic trophic models can be developed to express processes at the regional level. This requires a constellation of models, one for each hierarchical level within each vegetational cover class. Both terrestrial and aquatic models need to be structured so that linkages can be made, e.g., between a model for a stream and for a downstream lake to which the stream exports organisms, detritus, and nutrients. The terrestrial model can be linked to socioeconomic models, by expressing the portion of biomass in various compartments that are inputs to the human system. A regional ecological model could consist of modules on (a) air diffusion modeling, (b) hydrologic modeling, (c) terrestrial trophic modeling, (d) aquatic trophic modeling, (e) rare and endangered species and historical site mapping and computer retrieval of locations, and (f) concept development for human activity modeling. Such clusters of models do not appear to be operational at this time.

METHODS AND TECHNIQUES FOR MEASUREMENTS

Methods for measuring primary production and productivity appear in manuals prepared by the IBP and published by Blackwell

Scientific Publications, Oxford. These include: Neubould (1967), Ricner (1971), Milner, Hughes, Gimingham, Miller and Slatyer (1968), Golley and Buechner (1968), and Vollenweider (1969). Secondary production and productivity are covered in Petrusewicz and Macfadyen (1970), Edmonson and Winberg (1971), Sorokin and Kodota (1972), and in Grodzinski and Klekowski (1972). The harvest method is discussed Ovington (1957), Bray, Lawrence, and Pearson (1959), Odum (1960), Whittaker (1961, 1962, 1965), Kira and Sheidi (1967), Satoo (1970), and Bray and Dudkiewicz (1963). Methods for basal area proportions are found in Ando (1965) and other three measurements procedures are in Peterken and Newbould (1966), and Whittaker and Woodwell (1969). Gaseous exchange methods are discussed in Tranquilliri (1959), Mooney and Billings (1961), Odum (1965), and Woodwell and Whittaker (1968). Watson (1952), and Blackman (1968), provide growth analysis, and light chlorophyll relationships are given in Odum, McConnell, and Abbott (1958), Ryther and Yentsch (1957), and Bray (1960). Soil respiration measurements are found in Reiners (1968) and soil climate measurements in Szarnowski (1964). Evapotranspiration is given by Lieth and Box (1972), and by Lieth (1973). Also useful are Allen (1972), Inoue (1968), Odum (1956), Perry (1972), Odum and Kuenzler (1963), Petrueswicz (1967), Phillipson (1970), Schwoerbel (1970), Wineberg (1971), and Lieth (1974).

Transfers of energy and nutrients should be considered together in any assessment of ecosystems. Static chemical inventories can be supplemented by inferences about the flows of various elements (Ovington, 1962, 1965), Duuigneaud, and Denaeyer-DeSmet (1970).

A dynamic approach relies on radioactive tracers, isotopes of the elements under study. Olson (1968) discusses a transfer model which allows one to represent the proportions and probabilities of transfer of different elements within and between different compartments of the ecosystem as a matrix. Methods of tagging trees with radioactive isotopes and the results of the

the Oak Ridge investigation on mineral cycling are also discussed. Some methods for the study of soil microorganisms important to mineral cycling are described in Parkinson et al. (19710, and Phillipson (1971).

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CASE STUDY OF WASTEWATER TREATMENT FACILITY INVESTMENT AT LAKE GEORGE, NEW YORK

Richard A. Park and David P. Carlisle*

With mounting concern over the secondary effects on natural and agricultural environments, particularly from urbanization, it has become apparent that an objective, analytical strategy is necessary to assess the subtle, but far-reaching, impacts of wastewater treatment facilities (WTF) and highways. Because such a strategy could profit from recent interdisciplinary modeling experience and findings in ecosystem science, The Institute of Ecology (TIE) was given the charge of developing a generalized methodology.

The Institute of Ecology was asked to undertake one or more case studies, including preparing the ecology section for an Environmental Impact Assessment on a wastewater treatment facility, to validate or amplify the generalized methodology. Clearly the cost of implementing an entire EIS was beyond the resources available for this study. Thus, an existing or proposed wastewater treatment facility would have to be considered in an area where an adequate data base and ecological infrastructure was available. Specific attention was to be given to one of the biome types modeled by the US International Biological Program (IBP). Lake George, New York, one of the sites in the Eastern Deciduous Forest Biome, was chosen as the example for a case study, in part because of its proposed comprehensive sewerage project.

Since resources and time were limited the decision was made to pass through the steps and analyze the procedure rather than to emphasize the mere completion of EIS statement. Thus,

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the emphasis in the case study is on an amplification of the methodology rather than on achieving a complete end product. This constitutes an abbreviated version of the ecological section of an EIS.

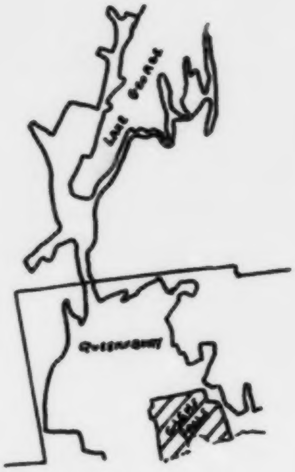


Figure 5-1.

Comprehensive sewerage study map, Glens Falls-Lake George, New York

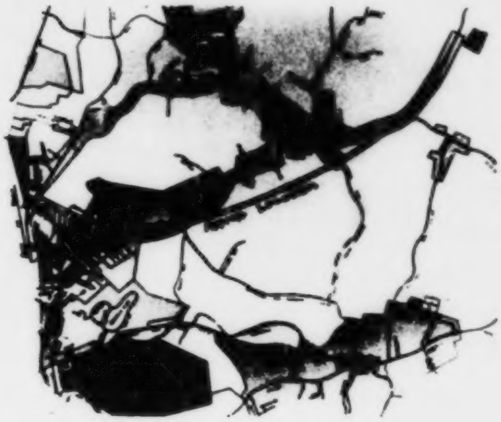


Figure 5-2.

Approximate location of suggested highway in town of Brunswick, Rensselaer County, New York

For illustrative purposes and to provide greater depth in testing the methodology, some of the data necessary to assess the effects of a proposed bridge and a supporting highway system in Rensselaer County, New York, were also considered.

In practice the generalized methodology can be expressed in the following simplified flowchart. The case study is intended to exemplify the elements and execution of this comprehensive approach. A more detailed version of the flowchart is presented in the Summary.

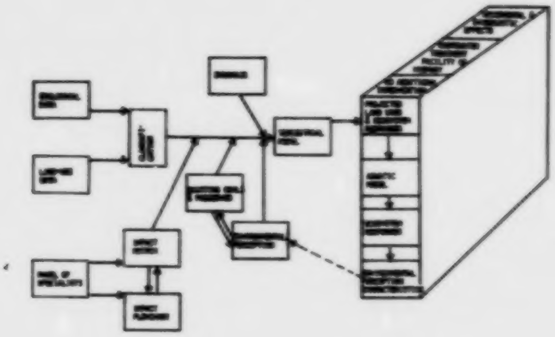


Figure 5-3.

Simplified flowchart for generalized methodology

DESCRIPTION OF THE EXISTING STATE

Land Uses

The New York State Land Use for Natural Resources Inventory (LUNR) dataset (New York State Office of Planning Services, 1974) was particularly valuable as a regional data source for the case study. Based on the interpretation of 1968 aerial photographs, this dataset enumerates 130 land-use characteristics useful for planning purposes (Appendix A) for each Km^2 cell. Availability of the data in computer-processible form (as well as on overlays) meant that the salient land-use characteristics of the 640 cells in the Lake George area could be displayed in tabular and map form at the beginning of the study. The data were extremely useful.

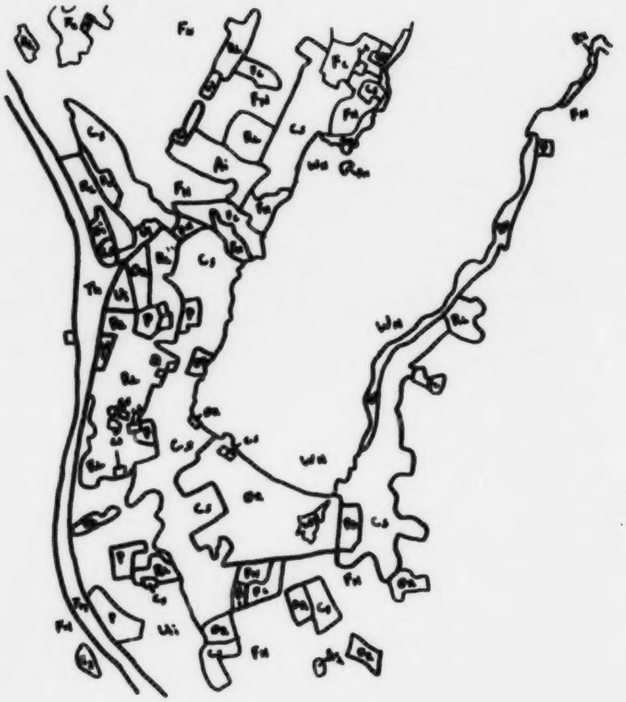


Figure 5-4. LUNR overlay showing land uses

A word of caution: regional data banks often contain abnormally large numbers of errors. Tedious analyses, encoding, and keypunching by individuals with no direct interest in the data take their toll. Therefore, data should be field checked and subjected to other tests for accuracy. In the case study the LUNR data were found to deviate consistently from the classification manual for certain categories such as marshes, hamlets and estates. Consequently, allowance was made for this idiosyncrasy in interpretation (which was probably specific for the photo interpreter who worked on the Lake George photos).

Forests

LUNR does not subdivide forests into types, yet the vulnerability of the various Adirondack forest types to human impact differs considerably. Therefore, it was necessary to augment the LUNR data base with vegetational data gathered by a graduate student in biology. Using field checks and stereopairs of U-2 color infrared photos available from NASA (obtained through the New York State Geological Survey) he was able to delineate the 7 principal forest types for an area of 640 square kilometers in approximately 4 days. This information formed the basis for modeling forest types in the impact area.

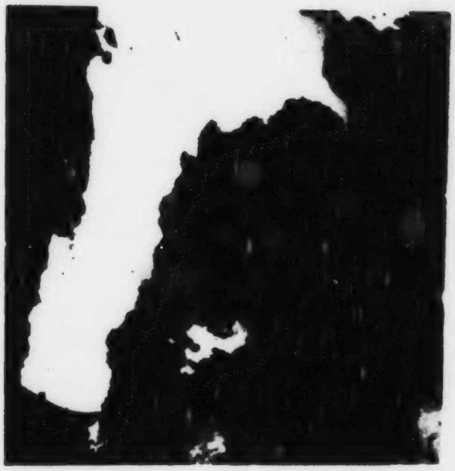
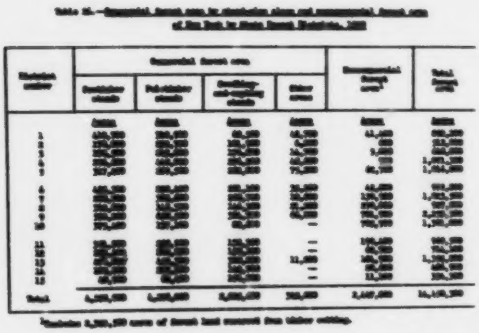
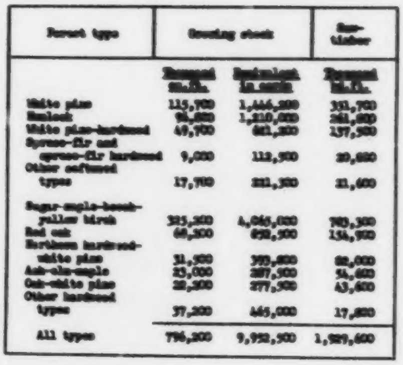


Figure 5-5.

Print of U-2 Infrared Imagery: Original in Color

Commercial forest statistics by district and forest survey data by county were available from the U.S.D.A. Forest Service, but these data are too coarse for most impact studies. For the Lake George study area, data were also available from the Department of Environmental Conservation foresters and from the Adirondack Park Agency community-reimbursement tax files. In addition, data are available on forest production by county (Ohlsen, 1956). These data were found to be of little use in our study.





Forest type	Growing stock		Saw-timber
	Thousand cu.ft.	Equivalent in cords	Thousand bd.ft.
White pine	115,700	1,446,200	331,700
Hemlock	[illegible]	1,210,000	261,600
White pine-hardwood	49,700	681,200	137,500
Spruce-fir and spruce-fir hardwood	9,000	112,500	[illegible]
Other softwood types	17,700	211,300	21,600
Sugar-maple-beech-yellow birch	325,200	4,065,000	703,300
Red oak	68,300	858,500	134,900
Northern hardwood-white pine	31,500	393,800	82,000
Ash-elm-maple	23,000	287,500	54,600
Oak-white pine	28,300	277,500	43,600
Other hardwood types	37,200	465,000	17,800
All types	796,200	9,952,500	1,929,600

Figure 5-6.
Examples of available forest statistics

Wildlife

Wildlife data were more difficult to obtain. Data on game animals whose hunting is controlled are available from state wildlife biologists. However, this is restricted to numbers legally taken; in the Rensselaer County case study area the deer data are unreliable because the majority of the deer are taken illegally (Vance, personal comm.)! Furthermore, this is due in part to the proximity of an urban area. The presence of other animals including rare and endangered species can be inferred by the presence and continuity of suitable habitats. If accurate wildlife data were deemed important, it would be necessary to conduct surveys, including road traverses at times of peak animal activity, noting animal crossings and calls. We felt that the qualitative and semi-quantitative information available from experienced wildlife biologists was sufficient for judging potential impacts.

Fish

Fish data could have been obtained through creel censuses and Fish and Wildlife stocking records, but would have been biased toward key game species. Again, the habitat approach (noting temperature, bottom type, and availability of food) could have been used to indicate presence of different forms. Detailed surveys are impractical because of resource requirements and the impossibility of getting accurate data for most species, as indicated by the IBP experience at Lake George.

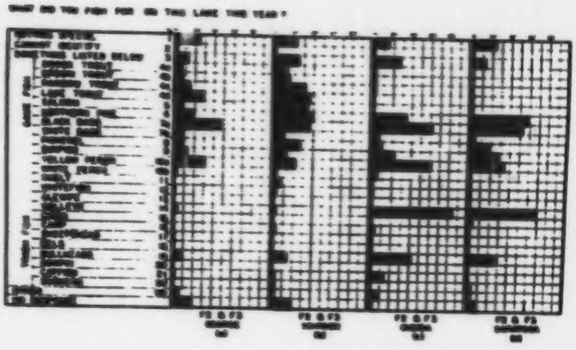


Figure 5-7.

Fish species sought by fishermen at four lake study areas (Kooyoomjian, 1974)

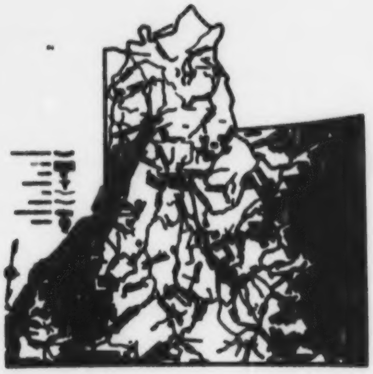


Figure 5-8.

Location of stocked streams in Warren County, New York (NYS Department of Environmental Conservation)

Other Aquatic Life

Because Lake George has been intensively studied by the IBP, seasonal biomass patterns are reasonably well known for other trophic levels. However, few lakes have been so thoroughly studied because manpower, funding and time are limited. If the lake ecosystem is of concern, minimal data requirements for impact analysis are: winter dissolved phosphate level, summer chlorophyll values, and some indication of the summer phytoplankton composition (diatoms, green and blue-green algae). These can be

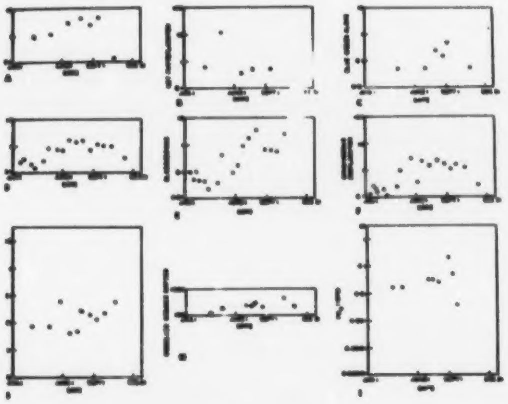


Figure 5-9

Lake George biomass data

obtained with little effort; but, obviously, advance planning is necessary! Depending on conditions, dissolved oxygen and/or biological oxygen demand measurements may be sufficient for streams already heavily impacted. Otherwise, bottom fauna and fish are useful indicators of the condition of stream ecosystems. The Lake George data were used to calibrate CLEANER, an aquatic ecosystem model, so that detailed impacts could be forecast.

Agriculture

Agricultural census data including crops, acreages and income, were available from the U.S. Department of Agriculture. Because these are listed by county, application to the impact area requires some extrapolation. If the objective had been to actually write an EIS, the County Agricultural Extension Agent would have been consulted. A publication on the "Economic Viability of Farm Areas in New York State" (NYS Office of Planning Coordination, 1969) is of some help. Similar inferences could be made using the agricultural census data and a soil map. Depending on the

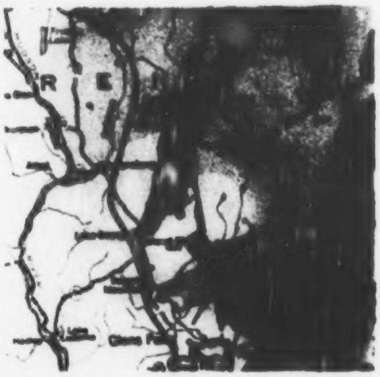


Figure 5-10.
Darker Shading Indicates Greater Viability of Farm

status of agriculture in an impact area, this information may be essential (agriculture is insignificant in the Lake George region).

Soils

Soil maps were available from the U.S.D.A. Soil Conservation Service for both the case study areas. Furthermore, an extensive catalog of soil uses is available in draft form for New York State (Cornell University, 1972).

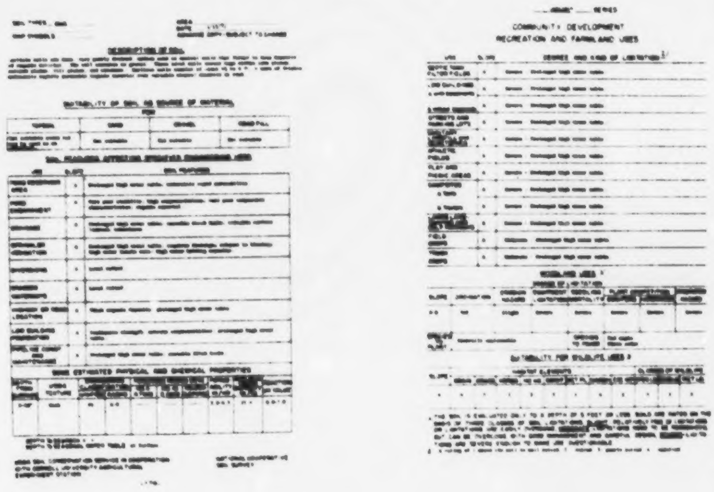


Figure 5-11.
An Example of Soil Usage Information (Cornell University, 1972)

Soil capability maps were also available, presenting in summary form the soil limitations on construction.

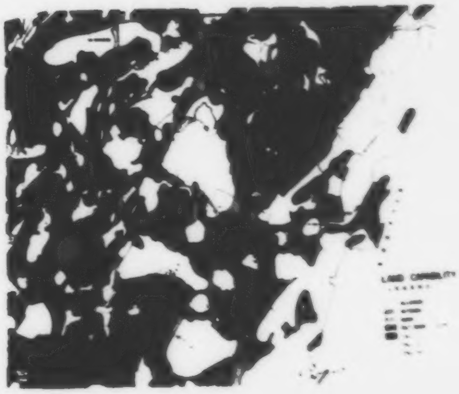


Figure 5-12.
Land Capability in Rensselaer County, New York

Topography

Information on elevations, slopes, and topographic "grain" were easily obtained from U. S. Geological Survey topographic maps. Such information is important in understanding patterns of microclimatic control on vegetation and the disposition of corridors for future development and transportation. Taken in conjunction with soil characteristics, the slopes indicate impediments to urban growth, which should be considered in the environmental analysis. We incorporated the mean slope for each Km^2 cell into a dataset to be used in modeling.

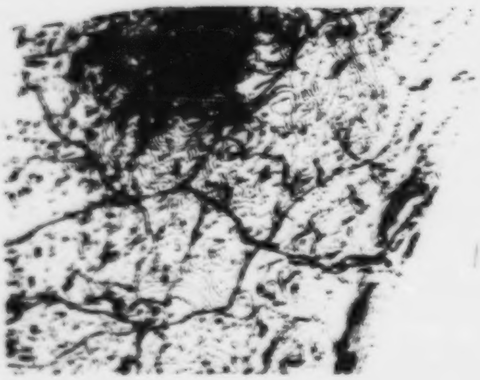


Figure 5-13.
USGS Topographic Map for Brunswick, New York

Figure 5-14.
Slope Map for Brunswick, New York

Figure 5-15.
Map Showing Impediment to Growth in Lake George Area

Hydrology and Geology

Hydrology and groundwater hydrology data could have been obtained from the U.S. Geological Survey, with particular attention to surface and groundwater flow records and to the distribution of recharge areas. Depths to the water table could have been inferred from the soil map. In actuality these data were available through the I&P study and through a comprehensive study of the town of Lake George conducted by the Adirondack Park Agency. Such data are necessary for preparation of an adequate EIS.

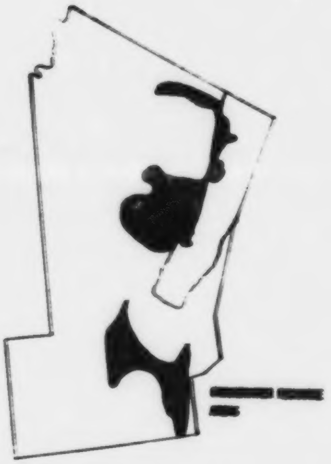


Figure 5-16. Groundwater Recharge Area, Town of Lake George, N.Y.

Geologic data may be of prime importance in regions where factors such as slope instability, drainage, or deflation are problems. Reports describing and mapping the surficial geology of both Lake George and the region that includes Brunswick are available from the NYS Geological Survey. For these regions knowledge of the surficial geology was of little additional help.

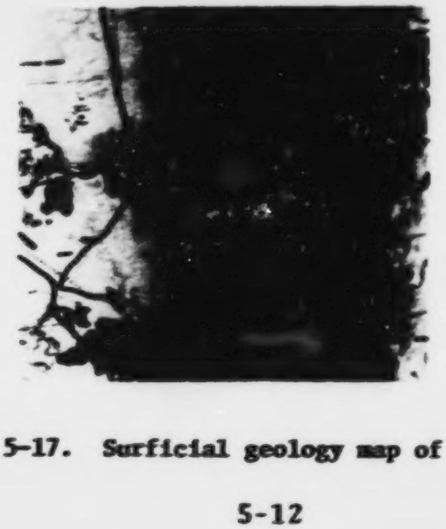


Figure 5-17. Surficial geology map of Capital District

Figure 5-18.
Location of Glacial Sand Deposits in the Capital District

Water Chemistry

Extensive data on water chemistry are available for Lake George and its drainage basin because of the IBP study and the interest of the NYS Department of Environmental Conservation. This has facilitated the computation of a nutrient budget for Lake George (Table 1). A similar budget should be prepared for each major water body in an impact area. Increasingly data are available from local sources. The water chemistry of two reservoirs in the Rensselaer County study area have been analyzed, first by a National Science Foundation sponsored student research project and later by concerned town Conservation Advisory Councils. If data had been lacking, guesstimates would have been made on nutrient loadings using the findings of Shannon and Brezonik (1972) and other, more recent, EPA-supported studies.

Climate

Climate data were obtained in tabular and computer-processible form from N.O.A.A. for the weather stations near Lake

Table 5-1

Estimated Phosphorus and Nitrogen Budget for Lake George, New York; Courtesy of N. L. Clesceri, D. B. Aulenbach, and J. J. Ferris

	Phosphorus		Nitrogen	
Sources	kg	% of Total Sources	kg	% of Total Sources
Runoff	2890	37.1	86,700	43.1
Precipitation	2400	30.8	84,600	42.1
Sewage Treatment Plant Effluents	0	0	18,000	9.1
Septic tank Effluents	2300	29.5	9,580	4.8
Lawn Fertilizer	208	2.6	2,080	1.0
Total	7800	100	201,000	10.0
Sinks		% of Total Sinks		% of Total Sinks
Outflow at Ticonderoga	2040	26.2	62,800	31.2
Sedimentation	5760	73.8	138,000	68.8
Retention		73.8		68.8
Surface loading	0.0684 $g/m^2/yr$		1.76 $g/m^2/yr$	

George. Adjacent weather stations provided insights into the micro-climate effects in the area. In particular, the difference in elevation of the Glens Falls Airport and the Glens Falls Farm station often results in a pronounced difference in late spring snowfall - a difference that affects the distribution of plant communities and that results in costlier snow removal (and better skiing) for the higher elevations. However, we did not use this information directly.

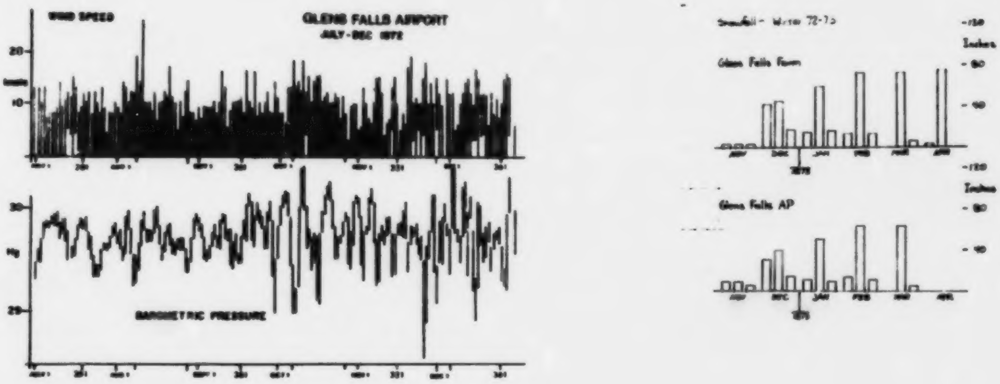


Figure 5-19. Weather Records (plots courtesy of S. Katz)

ANALYSIS OF DATA

Mapping

Most data were already available in map form (see above). With the data in machine-processible form, which is a requisite for most analyses, it was also possible to take advantage of programs that are generally available for the routine mapping of spatial data using computer facilities.

SYMAP, a series of programs developed at Harvard, is available at many computer centers. For the Lake George study we used the LUNR-compatible PLANMAP program - an offshoot of SYMAP developed by Cornell. The program is able to search through the regional data base, locating cells with the combination of characteristics specified by the user. The data values can be weighted, and cells meeting specified criteria can be excluded in the printing (for example, cells with a large percentage of water as shown above). Use of overprinting results in a highlighting of patterns that can be visually interpreted. In the Lake George area we found that because of inappropriate choices of colors to denote differing densities of characteristics, the resulting maps were more easily interpreted than the corresponding color maps that were available.

Figure 5-20.
PLANMAP Output showing Forest Cover in the Lake George Region

Multivariate Analysis

With the data in computer-processible form other procedures were also used to search for environmental relationships - procedures that can consider a number of co-occurring characteristics simultaneously. These are referred to as multivariate techniques and are primarily useful in permitting the impact analyst to gain a "feel" for the data quickly and objectively.

Cluster analysis - was used to classify two different sets of data into respective groupings.

The land-use data were clustered in order to determine existing patterns of usage in the Lake George area. First the characteristics were analyzed in order to identify the characteristics that tend to occur together - including the obvious grouping of lake and lakeshore characteristics and the less obvious grouping of income-intensive horticulture, specialty farms and light manufacturing with utility lines. Cells that were similar were also identified and, by means of a matrix presentation, they were compared with the clusters of characteristics in order to understand the overall patterns of land use in the impact area.

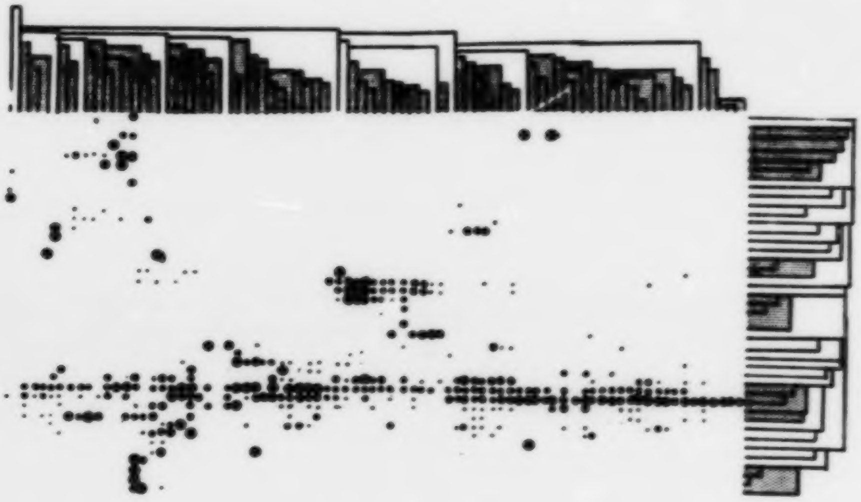


Figure 5-21.

Comparison of Clusters of Cells and Clusters of Land Uses; Diameters of Circles are Proportional to Area of Land Use in Cell

The ecological data were also clustered in order to determine ecological types that occur in the area. These were then mapped.

A similar approach had previously been used by Bloomfield (1972) to classify sediment samples from Lake George into environmental groups on the basis of their constituent diatom compositions.

Figure 5-22. Environmental Groups of Diatom Samples (Bloomfield, 1972)

Ordination - using the same basis for computation of similarities as cluster analysis, points representing the cells were arrayed in two-dimensional space on the basis of their dissimilarities to each other, and available information was plotted in the resulting model. Of particular interest is the way in which environmental gradients representing varying degrees of environmental impact were inferred from the distribution of diatoms in the study by Bloomfield (1972). The clusters were mapped over the area of the lake using patterns chosen to emphasize the nutrient-enrichment gradient. The relationship between nutrient enrichment and villages around Lake George is evident and is a strong indication of the need for better sewage treatment.

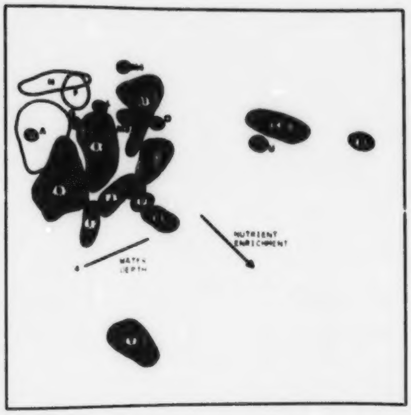


Figure 5-23.
Ordination of Diatom Samples and Clusters (Bloomfield, 1972)

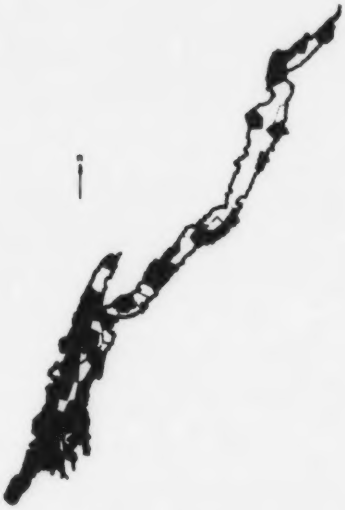


Figure 5-24.

Map of Diatom Groups in Lake George; Density of Pattern is Indicative of Nutrient Enrichment (Bloomfield, 1972)

ENVIRONMENTAL GOALS

Ecologically Sensitive Areas

The identification of sensitive ecological types may arise from the multivariate analysis (see above) or may be the result of a substantive study by a panel of specialists. A survey of the Town of Lake George by Adirondack Park Agency personnel resulted in the identification of nesting grounds, deer yards, and bogs harboring a rare and endangered species of turtle. These were considered to be unique natural areas worthy of protection. Likewise, wetlands, stream banks, sand plains, and steep shorelines critical to the functioning of the ecosystem were identified.

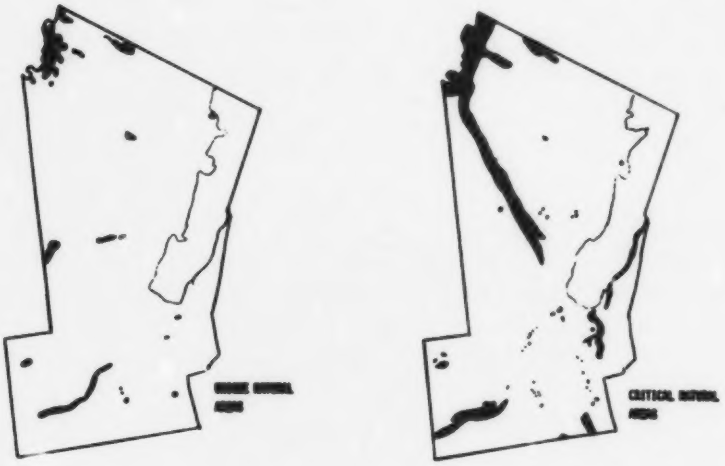


Figure 5-25. The Locations of Unique and Critical Natural Areas in the Town of Lake George (Adirondack Park Agency)

During the course of the case study public parks, forest-preserve tracts and environmentally-oriented recreation areas were noted. The location of archaeological and historical sites and houses might also have been noted, as in the Brunswick area.

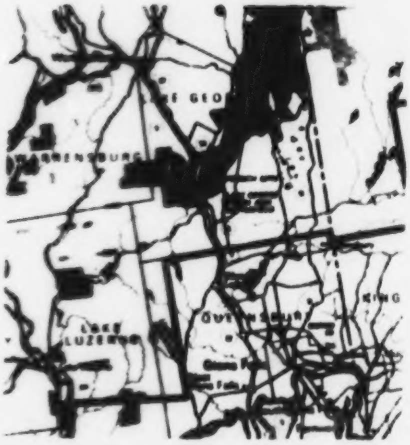


Figure 5-26.

Location of Parks and Forest-Preserve Tracts in the Lake George Region (as denoted by dark shading)

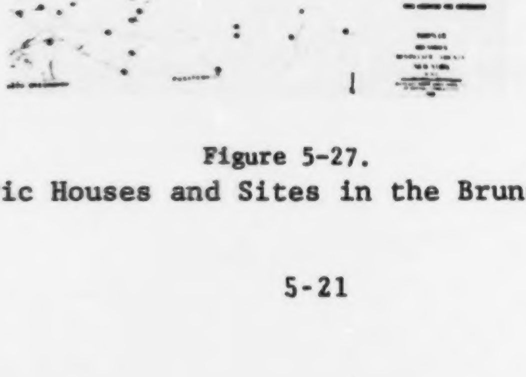


Figure 5-27.
Historic Houses and Sites in the Brunswick Area

If the area were fossiliferous, unusual and unique fossil localities would have been noted (one does occur just north of the Brunswick area). Likewise, mineral and rock localities should be recorded and afforded protection.

Environmental Perception

Identification of scenic vistas and open spaces that should be protected was based on driving through the area and subjectively evaluating the views.

Lake George

Brunswick

Figure 5-28. Scenic Vistas Worthy of Protection

Identification of other aesthetic characteristics is a little more difficult. Questionnaires have been used at Lake George and at three other lakes with dissimilar characteristics to determine the environmental perception of recreationists, cottage- and homeowners and businessmen (Kooyoomjian, 1974; Kooyoomjian and Clesceri, 1974). Data are available showing how each of these groups and constituent sub-groups perceive numerous aspects of the lake environment. Considering that the response may be positive or negative, the data can be used to predict differing usage patterns for a range of water-quality states.

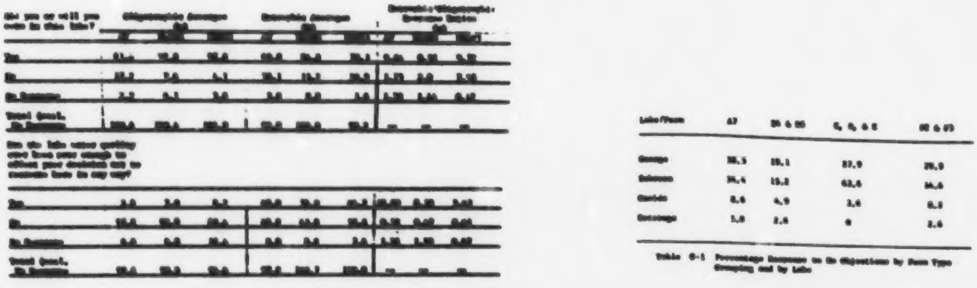


Figure 5-29.

Survey Results Indicating Effect of Water Quality on Recreational Usage at Oligotropic (George and Schroon) and Eutrophic (Oneida and Saratoga) Lakes; A7-general recreationists, B4 and B5-cottage and homeowners, C, D and E-commerce, F2 and F3-fishermen (Kooyoomjian, 1974)

Such a survey is very time-consuming. However, a simple, easily analyzed questionnaire can be used to answer the basic question: What environmental aspects do the residents consider worth saving or improving?

Existing Land-Use Plans

The Lake George case study area is largely within the Adirondack Park and is therefore protected by a comprehensive land use and development plan. The plan is based on consideration of: existing uses and growth patterns, physical limitations of soils and slopes, unique features, wildlife habitat, rare or endangered fauna and flora, fragile ecosystems, historic sites, proximity to critical state lands, and the need to preserve the open-space character of the Park. However, the "intensity guidelines" for privately-owned lands permit a density of housing in excess of that presently in much of the area other than Lake George Village. Clearly, if the construction of the wastewater treatment facility were to stimulate increased development, the Park plan in its present form would do little to discourage it.

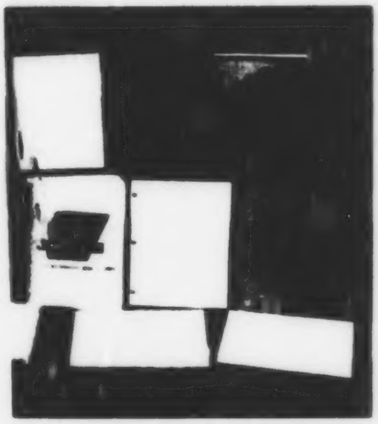


Figure 5-30.

Planning Documents, Pertaining to the Lake George Area

Figure 5-31.

Adirondack Park Agency Land Use Plan (APA, 1974)

For this reason, if this study were part of the preparation of an EIS on the sewerage system, consideration would be given to the zoning required to mitigate the effects of stimulated development.

ECOSYSTEM AND LAND-USE DYNAMICS

Historical Framework

Previous ecosystem states and responses provide a clue to the continuing vulnerability and resiliency of an area. Three approaches have been found to be useful in the Lake George area:

1. The most obvious approach is to examine historical records, which are readily available. The study areas were intensively farmed in the early 1800's, with sheep grazing the slopes that were too steep to till. However, soil erosion and other factors led to the gradual abandonment of agriculture.

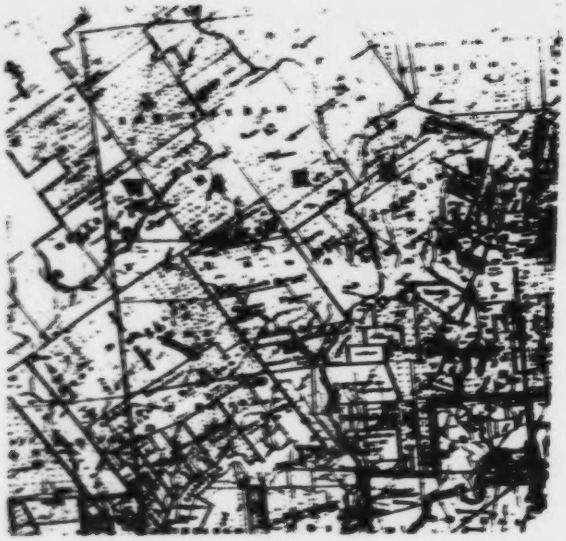


Figure 5-32. Original Plat Map of the Lake George Area

2. Consideration of the present forest ecology is also informative and readily accomplished. Most of the area is in a relatively early stage of forest succession, marked by dense underbrush, and both pioneer and successional tree species. Stone walls, fruit trees and naturalized herbs are the only direct evidence of the previous dominance by man. The ecosystem is well on the way to recovery, and the pattern of succession is evident.
3. Less easily obtained but of equal value are the findings of paleolimnology. The nutrient enrichment of Lake George correlates directly with the colonization by European Man as shown by the abundance of eutrophic-indicator diatoms in radiocarbon-dated cores. Furthermore, nowhere in Lake George is the present water quality comparable to that which existed prior to colonization (Del Prete, 1972).

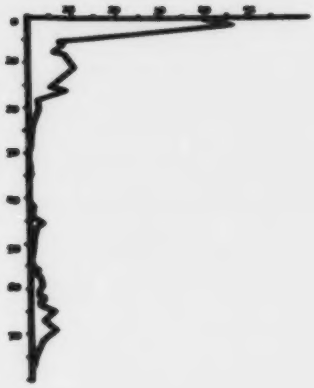


Figure 5-33.

Distribution of Relative Abundance of Eutrophic-Indicator Diatom Species, Expressed as Percentages of the Total Diatoms Samples at Each Level; Core Depth in cm. (Del Prete, 1972)

Recent Changes in Land Use

In order to predict the continuing changes that will occur without additional intervention it is necessary to have some baseline data on recent rates of change in land use. It is also necessary to determine the relationships of these rates to site-specific factors, such as soil types, slopes, and aesthetics.

In the Lake George case study, 1948 and 1958 photos were interpreted by a person with minimal training using the LUNR categories. Interpretation and encoding of 640 kilometer-square cells took only 3 days for each set, and the interpretations seemed to be more consistent than in the LUNR dataset.

The photo interpretations were augmented by wildlife records, agricultural census data, and forest data. Thus we were able to get hard data showing that agricultural lands in Warren County, of which Lake George is a part, dropped from 24,683 acres in 1964 to 10,601 acres in 1969 (USDA, 1972).

With compatible time-series data in machine-processible

form, it was possible to calculate yearly rates of change in land-use categories and to determine relationships to site-specific characteristics. Furthermore, computer-derived maps were printed for each characteristic and time period.

ANALYZING ENVIRONMENTAL RELATIONSHIPS

Models

The case study illustrates the use of two types of models that have arisen from the IBP Eastern Deciduous Forest Biome project. The first is an empirical model and the second is a functional model.

For the purpose of simulating land-use changes and accompanying terrestrial ecosystem changes in the Lake George area we adapted the land-use transfer approach of Hett (1971). Changes in land use were determined for a 20-year period using aerial photographs and supplemental data (see previous section). However, in order to assess environmental impact it was necessary to disaggregate the model spatially so that each Km^2 cell could be simulated separately according to its site-specific characteristics. These characteristics, such as slope, soil type, and zoning restrictions, were modeled as enhancement or reduction terms that would change the transfer rate. The submodel for medium-density residential property is given as an example.

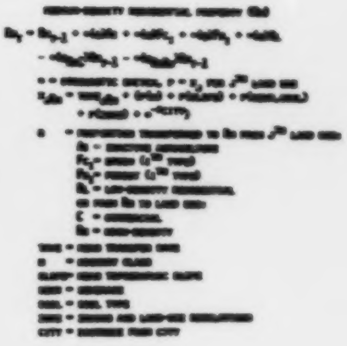


Figure 5-34. Medium-Density Residential Property Equation

A modified version of the forest succession model of Shugart, Crow and Hett (1973) was coupled to the land-use transfer model so that succession could also be simulated. The result is LAND (Land-use ANalytical Descriptor). The principal transfers are indicated below, where the categories (based largely on LUNR) are: Ac - corpland; Ai - inactive agricultural land; Fc - brushland; Fn - forest; Fp - pine plantation; Rk - shoreline residential property; Cs - shoreline commercial property; Fl, Rm and Rh - low-, medium-, and high-density residential property; and E - sand and gravel pits.

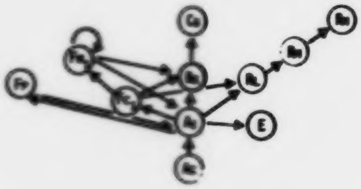


Figure 5-35.

Hierarchy of land-use transfers in LAND

Although there was not opportunity to implement it within the time constraints of the case study, our intent is to include a routine for predicting the presence or absence of selected wildlife species in each cell.

Information on preference of habitat, requirements for habitat continguity, and tolerance of Man was obtained through discussions with state wildlife biologists. With this knowledge it is a straightforward programming task to transform predicted land uses and forest types into species-specific habitats; even a mix of cover and feeding types can be considered as a linear combination of land-use and forest-type characteristics. Subsequently, with the exception of deer it can be assumed that if the habitat is present the animal will be present.

In order to investigate the impact that varying nutrient and siltation loads would have on water quality we used CLEANER, a simulation model that was first implemented for Lake George. CLEANER is a very complex model that embodies a great deal of information about the functionalities of lake ecosystems (Park and others, 1974). Because it has a functional basis, it seemingly can be used for a variety of lakes, with appropriate calibration (Park, Scavia and Clesceri, 1975). The model performs well for mesotrophic Lake George and eutrophic Saratoga Lake, New York. The generality of the model is presently being tested with data from six very dissimilar European lakes and reservoirs (Park, 1975). It can be accessed from remote terminals by EPA personnel using the Optimum Systems Incorporated (OSI) facility (Scavia, and Park, in preparation).

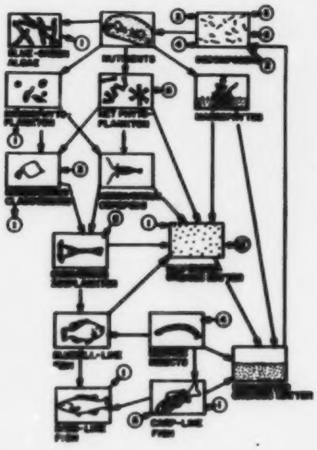


Figure 5-36.

Principal Compartments in CLEANER

Other models developed in the Eastern Deciduous Forest Biome were available but were not used in the case study because of difficulty in obtaining sufficient data. These models include TEEM (Shugart and others, 1974), which can be used in studying the dynamics of forest ecosystems, and HTM (Huff, 1972), which has proven useful in studying the effects of urban runoff (Huff and others, 1973).

If the impacts on the smaller lakes were investigated, as they should be in a full-blown EIS, then Vollenweider's (1969) model would have been used to predict algal response.

Impact Flowcharts

Many impacts are not amenable to modeling, but rather are best determined on the basis of the insights and experience of environmental specialists. The difficulty with this type of intuitive approach is that it does require a breadth of training in environmental sciences. Therefore, in order to implement it there should be an in-house team representing terrestrial and aquatic biology, geology, environmental engineering, agronomy-soils, and planning.

No attempt was made to develop an exhaustive flowchart for the case study. However, flowcharts are given in succeeding sections as indications of what might be done.

Matrix Approach

Attempts to use the matrix of Leopold and others (1971) in the Lake George study resulted in frustration because of the arbitrary nature of the ratings. Secondary impacts of wastewater treatment facilities and highways do not lend themselves to this type of superficial analysis. However, the detailed matrix of Rowe and Blackburn (1975) seems quite applicable and would have been used, with region-specific modifications, if an EIS were actually being written.

SEQUENCE OF ANALYSES

There should be a definite strategy for analyzing the environmental impact of an infrastructure investment, such as a WTF or highway. This strategy should embody a logical sequence of considerations, beginning with an examination of the effects of no action, proceeding through an analysis of project alternatives and finally weighing the consequences of further public investments necessitated by the resulting urbanization.

Projection of Change Without Additional Human Intervention

In order to assess the consequences of not building the wastewater treatment facility at Lake George, we would have run LAND using the assumption that previous land-use trends would continue, but in moderation because of recently inacted land-use legislation.

CLEANER was run assuming gradually increasing nutrient loading rates from the increasing numbers of septic systems. As one might expect, the predicted water quality gradually worsened as indicated by the increase in taste- and odor-producing algae, the increase in blue-green algae, and the decrease in the Secchi disc readings.

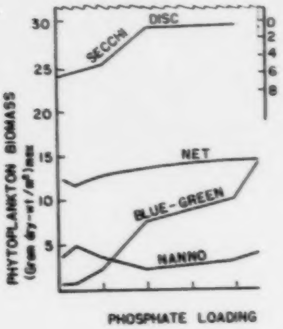


Figure 5-37.

Predicted changes in algae and Secchi disc readings

An impact flowchart prepared by a multidisciplinary team can formalize the consensus as to environmental relationships and can emphasize the trade-off between the primary impact of no action and the secondary impact of stimulated urbanization.

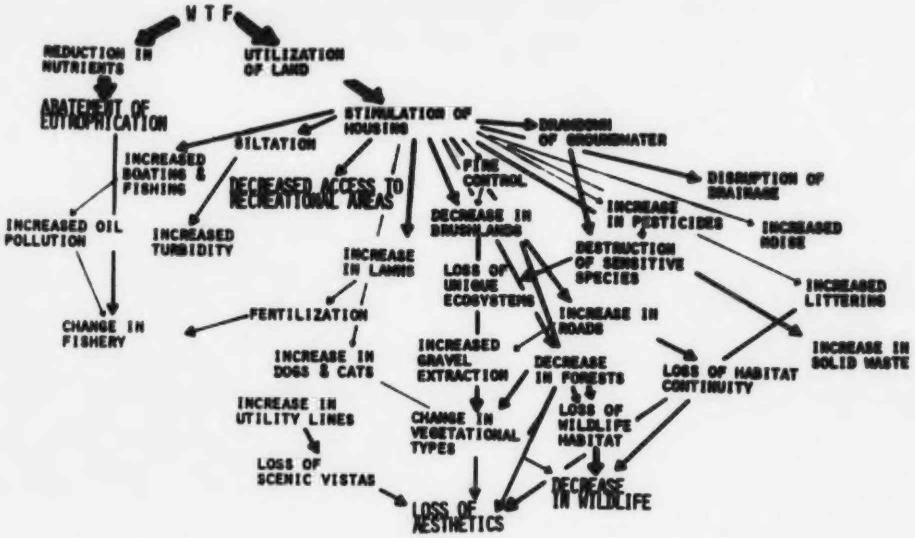

WTF
REDUCTION IN NUTRIENTS
UTILIZATION OF LAND
ABATEMENT OF EUTROPHICATION
STIMULATION OF HOUSING
DRAWDOWN OF GROUNDWATER
SILTATION
INCREASED BOATING & FISHING
DECREASED ACCESS TO RECREATIONAL AREAS
FIRE CONTROL
DISRUPTION OF DRAINAGE
INCREASED OIL POLLUTION
INCREASED TURBIDITY
DECREASE IN BRUSHLANDS
INCREASE IN PESTICIDES
INCREASED NOISE
INCREASE IN LAWNS
LOSS OF UNIQUE ECOSYSTEMS
DESTRUCTION OF SENSITIVE SPECIES
INCREASED LITTERING
CHANGE IN FISHERY
FERTILIZATION
INCREASE IN ROADS
INCREASE IN SOLID WASTE
INCREASE IN DOGS & CATS
INCREASED GRAVEL EXTRACTION
DECREASE IN FORESTS
LOSS OF HABITAT CONTINUITY
INCREASE IN UTILITY LINES
CHANGE IN VEGETATIONAL TYPES
LOSS OF WILDLIFE HABITAT
LOSS OF SCENIC VISTAS
DECREASE IN WILDLIFE
LOSS OF AESTHETICS

Figure 5-38. An example of part of an impact flowchart

Projection of Changes Accompanying Each Project Alternative

Implementation of the models LAND and CLEANER to examine developmental patterns and consequent effects on the terrestrial and aquatic ecosystems in relatively straightforward. Construction of a WTF removes the restriction placed on housing development by soils that are unsuitable for septic systems. This is handled in LAND by removing the site-specific soil reduction term, thus greatly increasing the probability of development in certain cells. The change from forest and brushland to lawns results in a change in nutrient loadings that can be "guesstimated" using the present relationships between loadings and land uses in the drainage basin (see Table 1). These new loadings are then used to drive CLEANER or to calculate new algal productivity using Vollenweider's empirical model (Vollenweider, 1969). Changes in primary and secondary productivity, including nuisance algae and fish, and in physical-chemical characteristics, such as water transparency, can be diagnosed directly using CLEANER.

Projection of the Incremental and Synergistic Effects

LAND could be used to investigate the incremental effects of a highway, whose construction would be justified by the increased development. Changing the "distance" or travel time parameter in LAND has a significant effect on subsequent predictions of development and hence ecosystem impact. To go a step further, by making road construction a dynamic variable in the program, the continuing effect of habitat subdivision on intolerant species such as bear could be simulated.

The formulation of a flowchart is helpful in presenting the subtle interrelationships of incremental effects. Due to the critical driving time to Glens Falls, the "gentleman farmer" effect exemplifies a possible relationship that may eventually occur in the case study area.

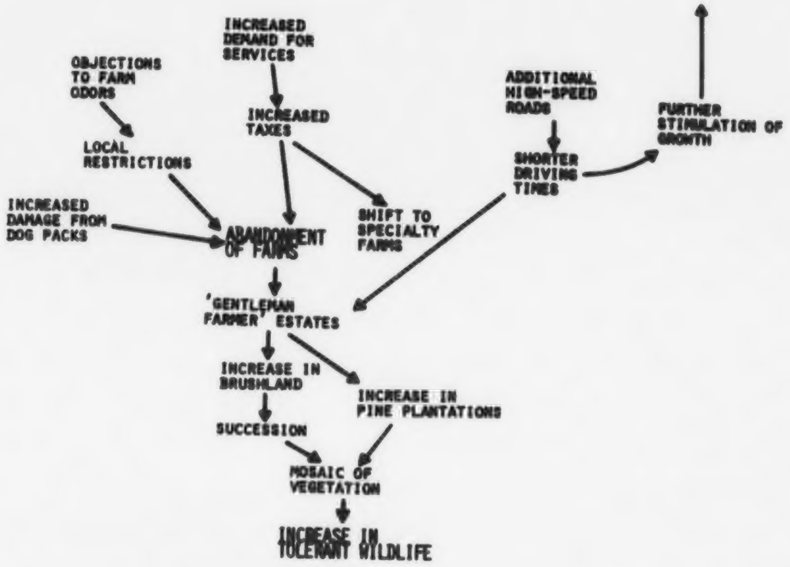

INCREASED DEMAND FOR SERVICES
OBJECTIONS TO FARM ODORS
ADDITIONAL HIGH-SPEED ROADS
INCREASED TAXES
FURTHER STIMULATION OF GROWTH
LOCAL RESTRICTIONS
SHORTER DRIVING TIMES
INCREASED DAMAGE FROM DOG PACKS
ABANDONMENT OF FARMS
SHIFT TO SPECIALTY FARMS
'GENTLEMAN FARMER' ESTATES
INCREASE IN BRUSHLAND
INCREASE IN PINE PLANTATIONS
SUCCESSION
MOSAIC OF VEGETATION
INCREASE IN TOLERANT WILDLIFE

Figure 5-39. Segment of Impact Flowchart with Incremental Effect Resulting in "Gentleman Farmer" Environmental Mosaic

SUMMARY

In summary, the case study, by means of selected examples, illustrates the implementation of the generalized methodology in a specific area and with a specific public investment. A detailed flowchart of the case study follows. It can be seen that the generalized methodology is both feasible and, with appropriate modifications, applicable to the needs of environmental impact statements and assessments in widely differing geographic areas.

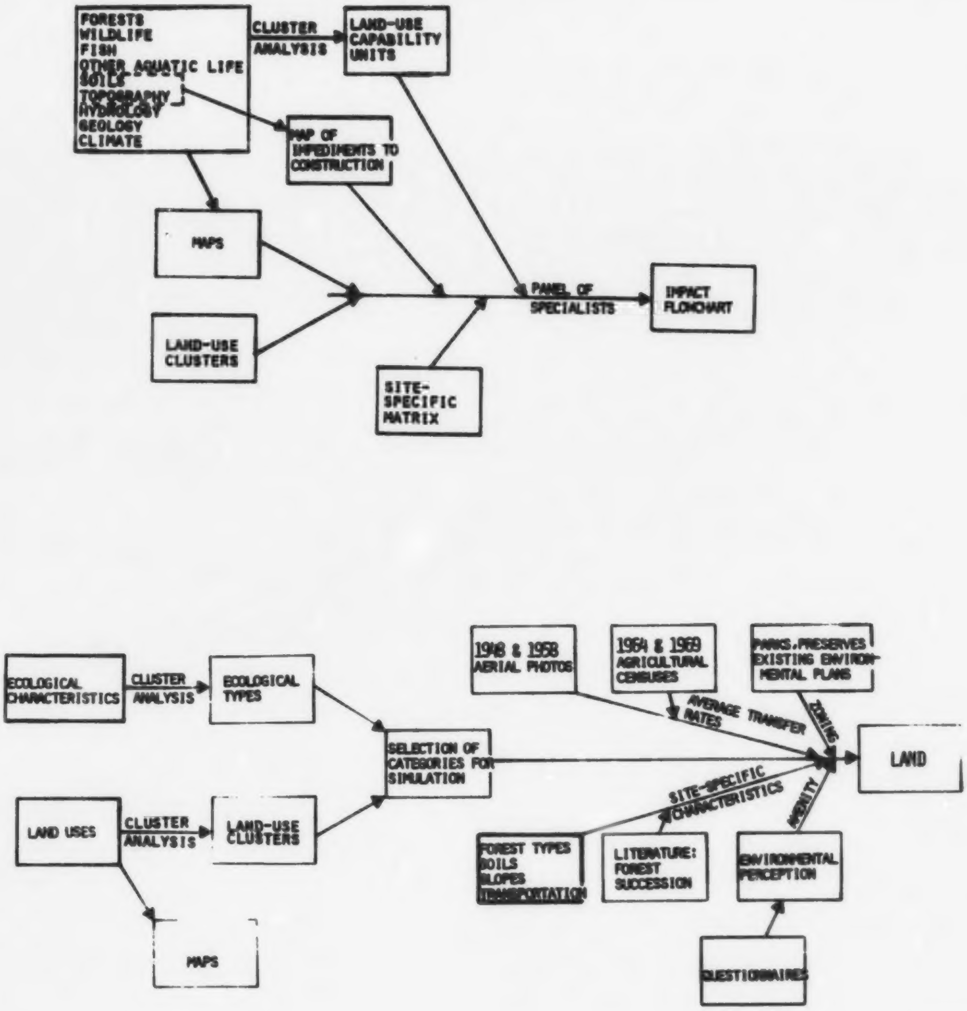

FORESTS
WILDLIFE
FISH
OTHER AQUATIC LIFE
SOILS
TOPOGRAPHY
HYDROLOGY
GEOLOGY
CLIMATE
CLUSTER ANALYSIS
LAND-USE CAPABILITY UNITS
MAP OF IMPEDIMENTS TO CONSTRUCTION
MAPS
LAND-USE CLUSTERS
SITE-SPECIFIC MATRIX
PANEL OF SPECIALISTS
IMPACT FLOWCHART
ECOLOGICAL CHARACTERISTICS
CLUSTER ANALYSIS
ECOLOGICAL TYPES
LAND USES
CLUSTER ANALYSIS
LAND-USE CLUSTERS
MAPS
SELECTION OF CATEGORIES FOR SIMULATION
1948 & 1958 AERIAL PHOTOS
1964 & 1969 AGRICULTURAL CENSUSES
PARKS, PRESERVES EXISTING ENVIRONMENTAL PLANS
AVERAGE TRANSFER RATES
ZONING
LAND
SITE-SPECIFIC CHARACTERISTICS
AMENITY
FOREST TYPES
SOILS
SLOPES
TRANSPORTATION
LITERATURE: FOREST SUCCESSION
ENVIRONMENTAL PERCEPTION
QUESTIONNAIRES

Figure 5-40. Flowchart of Case Study - Inputs to Land

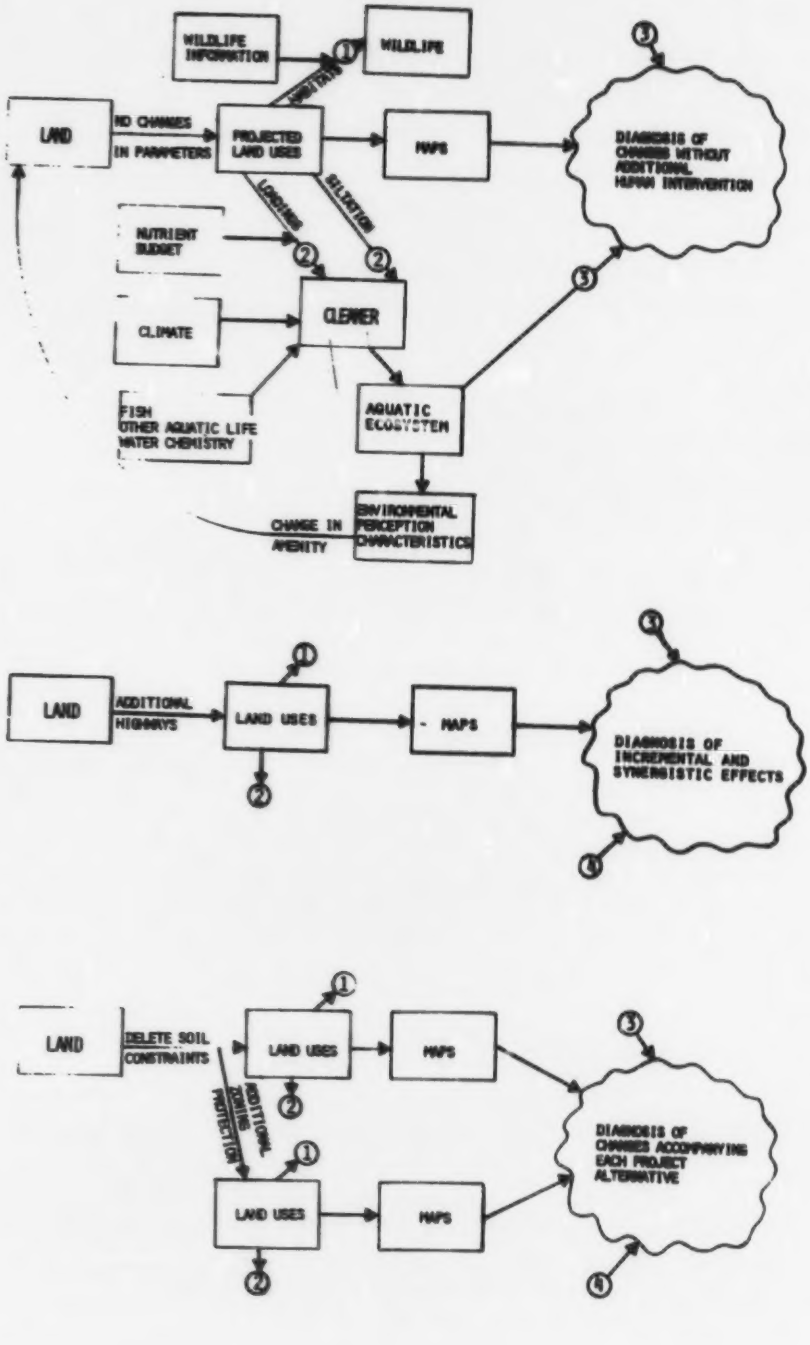

WILDLIFE INFORMATION
WILDLIFE
①
HABITATS
③
LAND
NO CHANGES IN PARAMETERS
PROJECTED LAND USES
MAPS
DIAGNOSIS OF CHANGES WITHOUT ADDITIONAL HUMAN INTERVENTION
LOADINGS
SILTATION
NUTRIENT BUDGET
②
②
CLIMATE
CLEANER
⑤
FISH
OTHER AQUATIC LIFE
WATER CHEMISTRY
AQUATIC ECOSYSTEM
ENVIRONMENTAL PERCEPTION CHARACTERISTICS
CHANGE IN AMENITY
LAND
ADDITIONAL HIGHWAYS
①
LAND USES
②
MAPS
③
DIAGNOSIS OF INCREMENTAL AND SYNERGISTIC EFFECTS
④
LAND
DELETE SOIL CONSTRAINTS
①
LAND USES
②
MAPS
③
ADDITIONAL ZONING PROTECTION
①
LAND USES
②
MAPS
DIAGNOSIS OF CHANGES ACCOMPANYING EACH PROJECT ALTERNATIVE
④

Figure 5-41. Flowchart of Case Study - Output from Land

ACKNOWLEDGMENTS

We are particularly grateful to Paul Marean, who was responsible for much of the biology and all the photo interpretations; without his contribution this case study would not have been possible. We are also very appreciative of the help and encouragement given by Carol St James in the earlier stages of the study. The assistance of Robert Haimes and Steven Chisick in programming and running multivariate analyses is likewise acknowledged.

Several agencies and many individuals were very cooperative in providing material during the course of the study. Among these are the staff of the Adirondack Park Agency, including Robert Craig; the staffs of several divisions of the New York State Department of Environmental Conservation, including Russell Mulvey, Steve Warne, John Hastings, Eugene McCaffrey and Merrill Robinson; Margaret Baldwin of New York State Office of General Services; Gloria Carey and Robert Crowder of the Office of Planning Services (now defunct); Marion Gardner, Lillian Jankowski and Arlene Larsen of Rensselaer's Office of Computer Services; and James Quinn of the Computing Center at the State University of New York at Albany.

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APPENDIX A - Land Use Categories in LUNR

- Agriculture
- Urban Inactive
- Forest Brushland
- Forest Lands
- Plantations
- Lakes and Ponds
- Artificial Ponds
  - Point Data
- Streams and Rivers
  - Mileage
- Marshes, Bogs
- Wooded Wetlands
- Residential
  - High Density
  - Medium Density
  - Low Density
  - Strip
  - Hamlet
  - Estate
  - Shoreline
    - Point Data
  - Rural Non-Farm
- Commercial
  - Central Business
  - Shopping Centers
  - Resorts
  - Strip
- Industrial
  - Light
  - Heavy
- Outdoor Recreation
  - Golf Courses
  - Ski
  - Public Pools and Beaches
  - Marinas
  - Campgrounds
  - Amusement Parks
  - Fairgrounds
  - Public Parks
  - Rifle Shooting
- Extractive Industry
- Public Lands
  - Solid Waste Disposal
  - Sewage Treatment
- Transportation
  - None
  - Township
  - Two- and Three-Lane
  - Four-Lane
  - Divided
  - Limited Access
  - Interchange
  - Gas and Oil Pipeline
  - Tel. & Elec. Transmission
- Non-Productive Rock

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	Town of Brunswick Zoning Map, Approved February 6, 1958.
Page 3	Original
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Page 5	NASA U-2 Photograph, April 30, 1973, Altitude 65,000 ft., F 6" lens, Color I.R. 9" positive, U-2 fl 73-063B
Page 6	Forest Statistics for New York, 1955, U.S.D.A. (p. 35).
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Page 22	Original Protographs
Page 23	Kooyoomjian, 1974
Page 24	Original Photograph
	A.P.A. 1971 Land Use Plan.

Page 25	Map in Warrensburg Regional DEC Office Showing Original Subdivisions.
Page 26	Del Prete, 1972.
Page 28	Land Model, Carlisle, Park, 1975.
Page 29	Modified from CLEANER, The Lake George Model In: Ecological Modeling in A Management Context (C. S. Russell, ed.), R. A. Park, D. Scavia, and N. L. Clesceri, 1975.
Page 31	Modified from Park, Scavia and Clesceri, 1975.
Page 32	Original
Page 33	Original
Page 34	Original

CASE STUDY -- WOODLANDS

Vicki Watson and David L. Jameson

As a part of the development of a methodology to assess the impact of urbanization on the ecosystem, a 'new town' was studied in some detail. The Department of Housing and Urban Development, under the Urban Growth and New Community Development Act of 1970, assists private and public efforts to provide a viable alternative to disorderly urban growth and to prepare Environmental Impact Statements on these projects. If approved, a Project Agreement between HUD and the developer results in a Development Plan which specifies pace, scope and details of development in short-and long-term periods. The developer is expected to comply to future standards of environmental quality.

Woodlands, a new community developing in Montgomery County, Texas, on the fringe of Houston, meets the criteria for Title 5 assistance. When fully developed, it will consist of all basic urban activities (housing, employment, commercial and institutional services and facilities, recreation areas and facilities, and light, non-pollutant type industry) and will place an ultimate population of 125,000 people on 18,000 acres.

Initial studies by Wallace, McHarg, Roberts, and Todd (1974) included ecological land planning physiography, geology, groundwater and surface water hydrology, limnology, soils, plant ecology, wildlife, climate, and an ecological synthesis. The developer takes the position that urbanization is, in any case, the projected result for the 18,000 acres and that his project is attempting to minimize the ecological impact while maintaining an economically viable development process. Since the data base was collected, we were able to analyze the Woodlands EIS using the steps in the developing methodology. This analysis led to alterations in the steps and identified some problems which we attempted to correct by modifying our procedures.

Two questions appeared worthwhile. What would have been the additional cost imposed by our procedures? Would our procedures be sensitive enough to identify acreages which should not be developed?

I. DESCRIPTION OF THE EXISTING STATE

a. Ecological units and categories.- Most of the area is natural woodlands (the various types are briefly outlined in the plant ecology section of the EIS). Except for the mixed-mesic woodlands, all the areas have been logged in the past, especially the loblolly pine-hardwood forest, the loblolly pine-oak-gum forest, and the pine-oak-oak-pine forest. This last is interrupted by several pipelines, old saw mill sites, drilling sites, and some urban development. Most of the forest area was being harvested until acquired by the present developers.

The grassland requires a special note. There are no climax or natural grasslands in the area; all are a result of human disturbances. Pipeline rights of way, oil fields, old saw mill sites, and some cultivated areas account for the grasslands. Grazing maintains the areas.

The total area involved in each of these ecological units should be measured and rate of transfer between types estimated.

The Woodlands provides a fair example of a conscientious attempt at describing the existing state of an area to be impacted by a project. In 1971, an ecological planning study was a part of a team of consultants planning a new town for Mitchell Energy and Development Corporation. Studies were made of geology, groundwater hydrology, surface hydrology, pedology, plant ecology, wildlife and climatology. The results of the studies undertaken by Wallace, McHarg, Roberts, and Todd are found in Woodlands New Community: An Ecological Inventory and are summarized here.

Geology -- The formations underlying the Panther Creek watershed are sands, gravels, and clays of Quaternary and Tertiary age. All formations strike roughly parallel to the Gulf Coast in northeast-southwest direction and dip toward the southeast at about 9 to 10 feet per mile. From the southwest to the northeast, the area is traversed by two geological formations. The more northwestern, more elevated soils are derived from the Willis sand of the Pliocene. The more southerly and southeastern soils are of the Lissie sands of the Pleistocene. Probably 75% of the area should be classed Lissie-Willis sands. This geologic mingling results in a broad, gently sloping transition from northwest to southeast. The terrain is moderately elevated in places, but is slightly undulating to flat over much of the central interior and southeastern extension.

Groundwater Hydrology -- All the water underlying the site comes from precipitation that falls on geologic outcrops north and northwest of the site and is conducted by slow percolation to great depths. During summer, most water entering the soil is lost by transpiration and evaporation. During fall, the water soaks down to regions of low permeability and when rainfall is heavy, a temporary, or perched, water table is formed. Later, what is not lost by evapotranspiration percolates down to the true watertable.

Potential yield of the aquifers beneath the site is estimated to be 20 MGD.

Surface Hydrology -- The Panther Creek Basin covers about 40 square miles and measures 95,040 feet long. Its stream gradient is .00159 feet/foot and its watershed has an annual runoff of 10 inches or about 21,000 acre-feet. At its mouth, Panther Creek's runoff flows at about 30 cfs, while at its confluence with Spring Creek its flow is 33 cfs if one adds subsurface flow. The Spring Creek Basin (southern boundary of the project) is roughly 10 times the area of the Panther Creek Basin and has an average flow of 207 cfs.

The hydrologic equation (inflow = outflow) mentioned in the first section may be stated as: (surface inflow + subsurface inflow + precipitation + decrease in surface storage + decrease in groundwater storage) = (surface outflow + subsurface outflow + evapotranspiration + exported water + increase in surface storage + increase in groundwater storage + consumption use).

A sample, conservative long-term water budget was done for Panther Creek watershed. Precipitation was found to be 45 inches/year and evapotranspiration was estimated to be 70% of that. Subsurface inflow was assumed to equal subsurface outflow. No increase or decrease in surface storage, groundwater storage, and soil moisture was assumed as was no import or export of water. This simplifies the equation to precipation = evapotranspiration + runoff.

TABLE 6-1. SAMPLE WATER BUDGET

Source	Amount in: inches/year	MGD
Precipitation	+45	+87
Evapotranspiration	-32	-62
Surface Runoff	-10	-19
Baseflow Runoff	- 3	- 6

In terms of management, maintenance of baseflow is the most important factor in the hydrologic cycle.

Pedology -- Soils on the site are red-yellow podzolic or by seventh approximate classification palendults and are characteristic of areas with a mild climate, abundant rainfall and a mixed conifer-deciduous forest cover. They are highly leached, acid in reaction, and fine in texture with a zone of clay accumulation. Organic debris is rapidly oxidized, and the area is low in organic matter content. Clays are kaolinite, lacking in a high shrink-swell ratio.

There are two basic types of soil on site. The more elevated, drier, better drained soils (Willis) are loamy sands with yellow brittle clay subsoils. The other soil type is deep, nearly level to gently sloping with variable drainage.

The majority of slopes on site are less than 5% except for the bluff area immediately north of Spring Creek (exceeds 10%). Slopes in excess of 5%, if disturbed, may require special consideration if greater than 100 - 150 feet in length.

Climatology -- Data from nearby airports describe the mild Gulf Coastal climate. On site micro meterological data are not available; these would certainly be desirable to understand both processes, ecological land use changes, succession, and overall environmental trends.

Plant Ecology -- The vegetation of the site is predominantly moist, mixed woodlands, dominated by loblolly pine (Pinus taeda). These pines are associated in forest climax with species of hardwoods, chiefly oaks (Quercus spp.), sweetgum (Liquidamber styraciflua), hickories (Carya spp.), typelo gum (Nyssa sylvatica), elms

(*Ulmus spp.*), magnolia (*Magnolia grandiflora*), and sycamore (*Platanus occidentalis*). Shortleaf pine (*Pinus echinata*) may dominate drier, more elevated soils, with a corresponding shift in associated hardwoods. Because of the pines and semi-evergreen understory trees, shrubs and vines, this forest type has been referred to as the Southeastern Evergreen Forest.

This area is reasonably complex, presenting a number of different forest communities. *Shortleaf pine-hardwoods* is a climax forest type occupying the more elevated, drier, sandy soil sites. Southern red oak (*Quercus falcata* var. *falcata*) is the most consistently occurring hardwood in their forest type and the understory is composed of sapling sweetgums, red and post oaks, sparkleberry (*Vaccinium arborium*), spatulate leaf hawthorne (*Craetegus spathulata*), American beautyberry (*Callicarpa americana*), yaupon (*Ilex vomitora*), St. John's wort (*Hypericum drummondii*). Vines include *Vitis*, *Smilax*, and *Rubus*, and grasses include *Uniola* and *Panicum spp*.

The four following types are basically *loblolly-pine-hardwood* associations recombined in varying ways. Therefore, communities represent a spectrum from mesic to semi-xeric and each is named by its associated hardwood species.

The largest and most varied of the vegetation types mapped was *loblolly pine-hardwood* found in the north central part of the project area. Red and post oak were consistent hardwoods, with sweetgum and tupelo gum in moister sites. The understory includes tree sparkleberry, little hip hawthorne, dogwood (*Cornus florida*), red bud (*Cercis canadensis*), rusty blackhaw (*Viburnum rufidulum*. Wetter sites exhibit hop-hornbeam (*Ostrya virginiana*), American holly, small tree yaupon, and American hornbeam (*Carpinus caroloniana*). Yaupon American beautyberry, and St. John's wort are common with *Sebastiana fruticosa* in heavier soils. *Vitis*, *Smilax*, *Berchemia*, and *Rubus* are common vines. Grasses include *Uniola*, *Panicum spp*., *Paspalum spp*., and *Axonopus*.

Loblolly-pine-oak-gum appears on deep, sandy, fertile loams in the southern part of the area. Loblolly pine, red oak, water and willow oak, sweet and tupelo gums dominate the overstory. The upper understory is made of American holly and hornbeam, hop-hornbeam, dogwood, red bud, tree sparkleberry, and hawthorns. The lower understory is America beautyberry, yaupon, hawthorns, and red bud. Vines are similar to last type.

Pine-oak-pine is the second largest type and occupies the eastern and southeastern portions of the area. This type is found on highly leached, poorly drained soils and has been heavily harvested. Includes post, water, and willow oaks. Pines were once important but were harvested out. Subordinate tree level is poorly developed, while yaupon dominates the shrub understory. Grasses and herbs resemble those of previously described areas.

Mixed-mesic woodlands is found in limited amounts in the northeast part of the area on soils of recent origin (fine sandy loam). Trees are loblolly pine, magnolia, a number of oaks and hickories, sweet and tupelo gum, American ash (*Fraximus caroliniana*), sycamore, and southern hackberry (*Celtis laevigata*). The lesser tree story has American holly and hornbeam, dogwood, hop-hornbeam, laurel cherry, red maple (*Acer rubrum*), red bay, *Aralia spinosa*, and river birch (*Betula nigra*). The lower understory is composed of arrowwood (*Viburnum dentatum*), shrub red bay, yaupon, possum-haw holly (*Ilex decidua*), sebastiana deerberry (*Vaccinium stamineum*), fringe tree (*Chionanthus virginicus*), and southern wax myrtle. Vines include *Vitis spp*., *Smilax spp*., *Ampelopsis cordata*, and poison ivy (*Rhus toxicodendron*). The herbaceous stratum is characterized by *Uniola*, *Panicum spp*., basket grass (*Oplis menus setarius*), *Elephantopus spp*., and *Smilax*.

Small stream flood plain or bottom land vegetation exists on poorly drained soils and boasts many fine old oaks. Other hardwoods include sweet gum, tupelo gum, winged and water elm, bitter pecan, hickories, and sycamores. American hornbeam, hop-hornbeam, and American holly dominate the lower tree story as yaupon, sebastiana, and deerberry do the shrub understory. Vines are those of the last type and herbs are represented by violets, cress (*Cardamine bulbosa*), buttercups (*Ranunculus*), pennyworts

(*Hydrocotyle*), mints (*Labiatae*), verbenas, rushes, and sedges. Grasses include switch grass, giant cane (*Arundinaria gigantea*), basket grass, and marshmillet (*Zozanopsis miliaceae*).

A number of wet weather ponds occur in the area and exhibit retarded vegetational succession. Few plants can adapt to the low mineral ratio, high water level, and grazing which characterize these areas. The typical pond is inhabited by a figworth (*Grastisla neglecta*), rush (*Juncus sp*.), and a tiny flatsedge (*Carex sp*.).

The grasslands of this area are largely man-created (pipeline rights of way, abandoned oil wells, old fields, and other disturbed areas). Carpet grass (*Axonopus affinis*), a sod-forming short grass, and common Bermuda grass (Cynodon dactylon), also a sod-forming perennial, account for most of the ground cover.

Wildlife -- Only a preliminary species list was compiled. Sixteen terrestrial mammals, four game birds, two waterfowl, eleven raptors, and more than two dozen other birds (and "song birds") are identified. About half of the mammals and a few of the birds are identified as common; the rest are rate.

The basic ecological units can be identified from the above studies because the animals' distributions and abundances are closely related to the identified plant communities. We, as a panel of two, are unwilling to explicitly limit the number of units, but some effort by a team of ecologists could do so, probably without additional data collecting. The absence of any analysis of the community interaction makes it very difficult to identify or project changes in amount and distribution of the ecological units which would occur in the area with human development.

b. *Identification and characterization of the dynamic ecological processes*.- Although a good start was made (especially on soils and hydrology), the Woodlands assessment of the existing state of ecological variables is inadequate. Particularly needed are measurements of terrestrial biomass and assessment of terrestrial primary productivity, including that of managed areas.

Once the productivity per unit area for each of the ecological land use types has been measured, total primary productivity can be obtained from the vegetation mapping which was already done. Terrestrial secondary productivity and decomposition studies will require much more work. The invertebrate and particularly the arthropod population of the area must be sampled and studied. Sollins' (1971) work may serve as a model. Studies of mineral and nutrient cycling are also needed.

A complete limnological study of the streams is necessary. Chemical parameters which need investigation are dissolved oxygen, temperature, pH, biological oxygen demand, ammonia, nitrates, phosphates, chlorides, alkalinity, and counts of total and fecal coliform bacteria. Physical sampling should include water depth, presence of riffles and pools, stream width, flow characteristics, silt deposits, organic sludge deposits, and iron precipitates. An investigation of the kinds and abundance of aquatic vegetation is needed. Biomass of phytoplankton and submerged macrophytes and aquatic primary productivity must be measured.

In addition to vegetation and wildlife the species composition of invertebrates, soil bacteria and fungi, and lichens, etc., should be investigated. The distribution, abundance, and demographic characteristic of old species is also necessary.

Organization of these species into food chains and webs is necessary for later modeling. Values of different energy and material flows should be measured; i.e., in the following example, the amount of energy transferred which each arrow represents should be measured. The very important impact of arthropods on plants must be investigated.

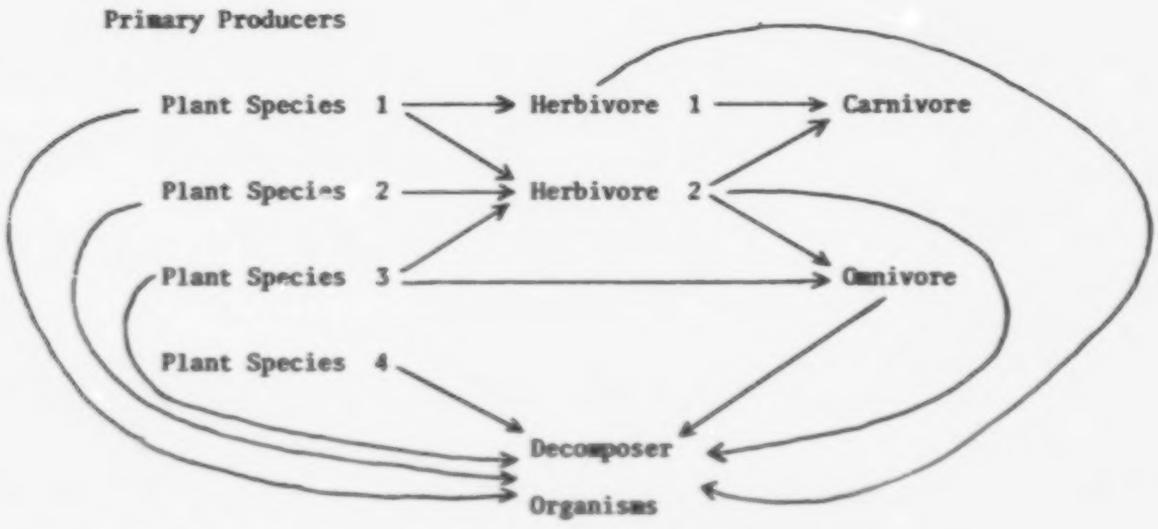
Primary Producers
Plant Species 1
Plant Species 2
Plant Species 3
Plant Species 4
Herbivore 1
Herbivore 2
Carnivore
Omnivore
Decomposer
Organisms

Figure 6-1. Sample food chain

Energy flow and material cycling may also be represented as in standard ecological texts. This would very probably show that the bulk of primary production goes directly to the decomposers; i.e., Woodlands is characterized by a detrital, rather than a grazing, food chain.

With regard to succession, the area is largely climax vegetation of the Southeastern Evergreen Forest except for areas which have been logged or cleared for grazing or cultivation. Most areas are now returning to the climax vegetation except for areas where grazing continues; these are being maintained in a grassland subclimax.

Seasonal variation also has an effect on the area, especially with regard to hydrology. A number of ponds and streams only exist during the wet season.

The total watershed picture must be investigated. The energy and material and water flow between terrestrial and aquatic systems must be mapped and values placed on the transfers and transfer rate. There is little aquatic habitat at present and the large increase which would come with one of the proposed alternatives (the building of Woodlands) would greatly increase this habitat. Its present relation to the terrestrial environment needs elucidation.

This assimilative capacity of all the ecosystem units (terrestrial but especially aquatic) for waste residual discharge and other human pertubations should be calculated. The amount of treated sewage and urban runoff (fertilizers, silt, oil, and gas, etc.) that the streams can assimilate without becoming eutrophic should be estimated (this value will vary with time of year). The amount of clearing that the forests can stand and remain viable as entities and as habitats for animals is of interest. The amount of noise and disturbances that animal population can assimilate without interfering with their activities should be considered.

c. Description of Historical Stage Setting.- The service area might be considered to be the 17,000 to 18,000 acres which will be developed while the impact area is much larger, including all waters downstream of Panther and Spring Creeks to Galveston Bay and the Gulf of Mexico and all areas which will provide support to the new community. A community such as this which is largely residential requires food and other consumer goods, power, employment and the transport of goods in and workers out.

While more or less natural forest woodlands account for a large percentage of the vegetation, the original structure of this area of Southeastern Evergreen Forest has been radically altered by repeated harvesting of the more mature pines and hardwoods, development of pipelines, drilling and storage facilities, some urban development, and forestry practices aimed at controlling the hardwood constituents. Some areas were cultivated earlier, and roads, both logging and improved, traverse the area. Cattle grazing and fire control have been practiced over most of the area for the past 30-40 years (McCloud, 1974). The sites and extent of the intervention should be mapped to provide a quantitative assessment of past human impact.

The first 20 years of the project should see the most radical changes in the service area because most development will be completed during this time. Significant time units of one year are indicated for the first 20 years and units of five to ten years afterwards. The larger impact area, however, will undergo more and more changes as the area becomes more developed, and the greatest impacts will occur toward the end of the 20-year development plan. Significant time units of five years for the first ten years, units of one year for the next 15 or 20, and then units of five years after this time seem plausible.

Past human population density, structure, and distribution should be investigated but will not be tremendously important in this largely natural and unpopulated area. Past human interventions (aforementioned grazing, cultivation, lumbering, fire control, etc.) are of more significance.

d. Description of Environmental Goals Related to the Ecosystem.- Sociologically, the primary environmental goal of the project was to provide an alternative to unplanned urban sprawl development. Ecologically, the main focus of the plan was to balance the hydrologic equation, i.e., see to it that water inflow equaled water outflow, in order to maintain hydrologic equilibrium. Actually, nature will balance the equation. Ecological planning must see to it thet this is accomplished with minimal deleterious changes in the environment.

Although the entire area is of great aesthetic value and serves as a natural buffer zone, assimilating pollution of nearby urban areas, some few vegetation types have been singled out as being worthy of special consideration and protection. Within a small area of typically mixed-mesic woodlands along the right side of Panther Branch, a small but unique area of flora has developed. Several Big Thicket plants of floral and botanical interest are noted here. Vegetation of the lower, small floodplain woodlands is almost unique in its beauty, tree species balance, wildlife possibilities, and remoteness. Other mesic woodlands near a proposed reservoir include fine specimens of large, attractive hardwoods which escaped harvest in the past. The numerous wet weather ponds and hummocks of the area also have unusual aesthetic possibilities (McCloud, 1974).

Local residents and environmental groups (in Houston, Sierra Club, Armand Bayou Nature Conservancy, and Citizens Environmental Coalition come to mind) should be consulted on goals for the project. State, regional, and local environmental plans which protect ecosystem structure and function should be considered.

The community development process approved by HUD allows changes in the Environmental Goals by the residential village governments. Thus, a village council in one area may approve plan changes which will conserve natural habitats, while another village council may decide that, because the ponds promote mosquito growth and the underbrush provides habitat for poisonous snakes, the ponds should be drained and the underbrush cleared. While this would promote a parklike atmosphere, it would reduce the habitat and species diversity and lower the number of Ecological Units and the variety of ecosystem processes.

e. Prediction and Description of Changes Without Additional Human Intervention (i.e. No Action Taken).- Developers, demographers, and planners consulted by the Woodlands Development Corporation claim that the area in question will become urbanized in the near future because of population pressure, regardless of whether or not the proposed planned community is built. Doubtless, this urbanization would be sprawl development typical of nearby Houston. Houston's land use distribution appears in Table 2. The area in question will very probably develop similarly, perhaps with a slightly greater percentage of land going to residential land use (it will no doubt serve as a "bedroom community" for Houston).

This 17,000+ acres might be exected to have around 40% of the area (i.e., 7,000 acres) in sinle-family, low-density residential housing with about ten peope per acre (using Houston's example). This would mean a populaion of 70,000, composed

TABLE 6-2. LAND USE IN HOUSTON, TEXAS

Single-Family (Low-Density)	30%
Residential Multi-Family (High-Density)	2%
Residential Urban-Commercial	12%
Industrial	10%
Open Space	4%
Undeveloped (Vacant lots, abandoned building)	43%

Data: Houston-Galveston Area Council. 1972.
Regional Data Book Vol. 1, p. 8, 68.

largely of upper middle and upper income groups. Doubtless, there would be also some high-density, multi-family residential areas -- probably around 2% of the area (350 acres) with 40 people per acre (looking again to Houston for land use and population figures). This would add another 14,000 people, bringing the population of the area to 84,000.

A study made by HUD (the costs of sprawl) asserted that unplanned "sprawl" development has a much greater impact on the environment than does "planned" development. The relative impacts of the two types of development on air and water quality appear in Tables 3, and 4. The values represent total effect per 10,000 dwelling units or per 33,000 people. The impact of a development may be calculated by multiplying the values in the tables by the number of people expected to inhabit the area and then divide by 33,000.

TABLE 6-3. POLLUTANTS/10,000 UNITS OR 33,000 PERSONS

Private Automobiles per Developed Acre (pounds per day)	Planned Mix	Sprawl Mix
CO	.8309	1.3050
HC	.1002	.1574
NO_x	.0978	.1535
Residential Natural Gas Use per Developed Acre (pounds per day)		
Particulates	.0342	.0374
SO_x	.0012	.0013
CO	.0008	.0008
HC	.0760	.0831
NO_x	.2281	.2494

Using the above population figures and the sprawl mix impact values from the tables, one finds sprawl mix development (i.e., both high- and low-density) would have the impacts shown in Table 6-4.

TABLE 6-4. WATER POLLUTION AND EROSION

Sediment from Erosion	**Planned mix**	**Sprawl mix**
Average annual volume during development period (tons per year[1/]	4,469.53	4431.09
Pollutants from Sewage Effluent		
Total Volume (liters per year)[2/]	4,559,032,500	Same as I
Pollutants (Kilograms per year)[3/]		
BOD	22,795.1	Same as I
COD	191,479.4	
N	77,503.6	
P	4,459.0	
SS	9,118.0	
FCB (number x 10^{-6} per year)	100% Removal	
Pollutants from Storm Runoff		
Total Volume (liters per year)[4/]	7,785,507,840	7,836,208,640
Pollutants (kilograms per year)[5/]		
BOD	181,402.3	182,600.0
COD	490,487.0	493,725.2
N	21,020.8	21,159.6
P	6,228.4	6,260.5
SS	7,785,507.8	7,836,908.6
FCB (number x 10^{-6} per second)	9,342,609.3	9,404,290.3
Pollutants from Sanitary Landfill Leachate		
Total Volume (liters per year)[6/]	4,095,616	Same as I
Pollutants (kilograms per year)[7/]		
BOD	66,437.3	Same as I
N	1,780.8	
P	28.7	
FCB (number x 10^{-6} per year)	482.8	

TABLE 6-5. AIR AND WATER POLLUTION

Air Pollution:

Pollutants from private cars (pound per day)

CO	9234.78	HC	1113.61	NO_x	1086.45

Pollutants from residential natural gas use (pounds per day)

Particulates	264.73	HC	588.31
SO_x	8.91	NO_x	1764.92
CO	5.85		

Water Pollution and Erosion:

Sediment from Erosion	1.13×10^4
(average annual volume during development period in tons per year)	
Pollutants from Sewage Effluent	
Total volume (liters per year)	1.16×10^{10}
Pollutants (kilograms per year)	
BOD	5.80×10^4
COD	4.87×10^5
N	1.97×10^5
P	1.14×10^4
SS	2.32×10^4
Pollutants from Storm Runoff	
Total volume (liters per year)	1.99×10^{10}
Pollutants (kilograms per year)	
BOD	4.65×10^5
COD	1.26×10^6
N	5.39×10^4
P	1.60×10^4
SS	1.99×10^7
Pollutants from Sanitary Land Fill Leachate	
Total volume (liters per year)	1.04×10^7
Pollutants (kilograms per year)	
BOD	1.13×10^5
N	4.56×10^4
P	7.31×10^1

Other relationships between land use and environmental quality may be discerned from Berry et al. (1974 table 2.7) Suspended air particulates may increase from 21 to 102g/^{m3} and several-fold increases in benzene, amonium, nitrates sulfates, copper, iron, manganese, nickel, and lead are expected. Some of the other effects of urbanizing this area follow.

Clear cutting increases the amount of water passing through the watershed in the form of runoff. This exposes the mineral soil and increases surface water temperature. The increase in flow from runoff is directly proportional to the amount of forest cut. Most significant change will occur during summer, the period of low flow, when stream flow will be greatly augmented. Erosion and siltation will increase, as will turbidity in streams.

Urbanization has one of its greatest impacts in its effect on water supplies. Some results of changing from a natural to an urban area are:

1. Large areas are covered by impervious areas that intercept precipitation and increase runoff, resulting in a reduction of groundwater recharge.
2. Storm drainage systems increase runoff, decrease recharge, and conduct polluted urban runoff into streams.
3. Large numbers of suburban septic tanks pollute shallow aquifers.
4. Municipal waste disposal pollutes streams and aquifers.
5. Urbanization encroaches on stream flood plains and banks, which previously served as natural water storage areas.
6. The resulting increased flooding will result in unstable devegated stream banks which results in further siltation and fertilization of water.
7. This results in increased growth of algae and plankton and increased turbidity of water.
8. Stream temperatures will be affected as more water is exposed to solar radiation and warm urban runoff enters streams.

Because of the flatness of the area, erosion will not be as great a problem as areas with "more topography" have experienced.

Other impacts of urbanization include: increase in ambient temperature (suburbs are 5° higher and urban centers 10-12° higher than undeveloped areas, according to Woodlands EIS), increase in noise level, increase in amount of wastes (both solid and liquid) to be disposed of, and decrease in area covered with photosynthetic plants.

Each of the ecological land-use types previously discussed will probably undergo urbanization. After modeling the manner in which the area would change if left natural with use of a succession model (Shugart et al., 1972, 1973) the effects of urbaniza- must be considered. The amount of area from which green photosynthesizing plants are removed and replaced by impervious structures is an important input to terrestrial productivity models. Each ecological land-use type has a different productivity and should be considered separately. An idea of the amount of difference in the productivity of a natural area and a nearby urban area may be obtained from table 4-4 comparing Noe Woods with the Nakoma residential areas. The amount of impervious surface is an input to hydrological models (as well as an input to water quality models). The amounts of waste residuals calculated earlier with respect to air and water pollution also serve as inputs to models (specifically process models of nutrient cycling and loading in aquatic systems).

With regard to changes from unidentifiable sources, there has been considerable similar development in this area and most sources of impact should have been identified. Since impact analysis is a new science (art?), even the most typical development will have impacts from unidentified sources, but this should be a small percentage of the total impact.

On the question of unpredictable change, decision-makers may visit any number of sites of sprawl development around Houston and see the impact for themselves.

TABLE 6-6. COMPARISON OF THE PRODUCTIVITY OF 'NATURAL' AND RESIDENTIAL AREA AT LAKE WINGRA. WISCONSIN

ECOLOGICAL PARAMETER	NOE WOODS	NAKOMA RESIDENTIAL
Total Above Ground Productivity g/m^2/yr (adjusted for impervious services)		
Trees	811.8	1009.8
Foliage (g/m^2/yr)	410.8	319.4
Branches (g/m^2/yr)	72.5	87.4
Bole (g/m^2/yr)	282.4	305.3
Shrubs (g/m^2/yr)	28.0	40.0
Herbs (g/m^2/yr)	18.1	257.5
Number species shrubs	12	74
Percent cover shrub	40	20
Number species trees	11	75
Density of trees (stems/ha)	422	143
Mean basal area trees D.B.H.	15-16	22-23

Data: Lawson, G. J., G. Cottam, and O. L. Loucks. 1972. Structure and primary productivity of two watersheds in the Lake Wingra basin. EDFB memo report 72-98.

II. DESCRIPTION OF CHANGES ACCOMPANYING EACH ALTERNATIVE

A. Alternative one - Development should be in the form of a new planned community

B. Alternative two - Area should be kept natural (development, whether planned or sprawl, should occur elsewhere), requiring revision of zoning or government purchase of land.

A. Rather than considering all the types of planned communities which could be built on the site, this description will concern itself only with that proposed by Woodlands Development Corporation. Obviously, communities could be designed so as to have even less impact on the environment with use of solar and wind energy, recycling of all wastes, high density housing, mass transportation, community gardens, etc. An examination of table 6-7 showing the proposed land use would show how much of each of the forest types would be involved in each of the ecological units.

A proposed 6,172 acres of housing (49,000 dwelling units) with 3.2 people per unit (156,000 people) will include both upper and lower income housing. Referring again to HUD (Costs of Sprawl, Table 2) Charts, one finds that a planned mix development (both high- and low-density) of this size and density (around seven to eight people per acre) would have the following impacts:

The quantitative discussion of impacts in the previous section need not be repeated here. Suffice it to say, qualitatively, impacts will be similar. Quantitatively, the air and water quality impacts appear to be greater for the planned than for the unplanned sprawl development. However, the planned development is also higher density than the unplanned (seven to eight people per acre, and five people per acre, respectively), so perhaps the values for planned high density and sprawl low density should have been used instead of the values for planned mix and sprawl mix. This would have brought the values closer together.

TABLE 6-7. PROPOSED LAND USE

a) Open space (3,359 acres) natural and parklike, 1/4 of total area, purpose - ecology and recreation.

b) Urban activities system (1,263 acres) business, recreational, institutional.

c) Industrial employment (2,005 acres).

d) Residential (6,172 acres).

Land Allocation in acres	
Total	16,939
Primary Open Space	2,798
Pipeline Right of Way	102
Primary Road System	1,513
Net Development Area	12,526
Infrastructure	1,615
Office Commercial	116
Comparison Retailing & Hotel	165
Industrial/Employment	2,005
Residential	6,172
Village Centers	493
Local Centers	339
Town/Univ. Center	150
Univ. Campus	400
Country Club/Golf Courses	270
Comm. Recreation Center and Golf Courses	250
Sports Facilities Complex	81
Stables	30
Secondary Open Space	561
Sewage Treatment	34
Reserve	1,460

TABLE 6-8. AIR AND WATER POLLUTION RESULTING FROM PROPOSED LAND USE

Air Pollution

Pollutants from private cars (pounds per day)

CO	11941.42	HC	1439.97	NO_x	1404.85

Pollutants from residential natural gas use (pounds per day)

Particulates	491.64	SO_x	16.54	CO	10.87
HC	1092.47	NO_x	3277.70		

Water Pollution

Sediment from erosion (average annual volume during development in tons/yr.	2.11×10^4
Pollutants from sewage effluent	
Total volume (liters per year)	2.16×10^{10}
Pollutants (kilograms per year)	
BOD	1.08×10^5
COD	9.05×10^5
N	3.66×10^5
P	2.11×10^4
SS	4.31×10^4
Pollutants from storm runoff	
Total volume (liters per year)	3.68×10^{10}
Pollutants (kilograms per year)	
BOD	8.58×10^5
COD	2.32×10^6
N	9.94×10^4
P	2.94×10^4
SS	3.68×10^7
Pollutants from sanitary land fill leachate	
Total volume (liters per year)	1.04×10^7
Pollutants (kilograms per year)	
BOD	2.10×10^3
N	8.46×10^3
P	1.36×10^2

Another difference between the two types of development is of significance. The planned community will base land-use decisions on ecological and hydrological considerations (permeability of soils, etc.) and will strive to minimize impacts with natural drainage systems, no development in 50 or 100 year flood plain, and maintenance of 1/4 of the areas in a "natural" state. The extent to which this lessens the impact of the project must be calculated in order to compare it to the no-action alternative.

Once again, the air and water quality impacts change in vegetation cover, and areas involved in various ecological land uses provide inputs to process and total ecosystem models. The results of this analysis should then compare to the analysis of the no-action alternative.

B. The last alternative (maintenance of the area in its "natural" state) requires only a brief note. It is highly unlikely that a conservation-minded private citizens or public organization will purchase the area and keep it natural. Perhaps it might be bought for agricultural or lumbering purposes. The effects of such management practices could also be assessed by process and ecosystem models.

III. DESCRIPTION OF INCREMENTAL AND SYNERGISTIC EFFECTS

The area in question is very near to one of the fastest (if not the fastest) urbanizing areas in the United States. This is the Houston-Galveston area of the Texas Gulf Coast. Probably because of its status as an energy exporting area, this part of the country is experiencing little of the effects of the present recession. Without a doubt, the development of this area (the area recently acquired by Woodlands Development Corporation) will add a very significant increment to the urban areas surrounding and including Houston and Galveston. Almost certainly, further development will be stimulated by that peculiar cancerous habit of urbanization which always seems to make its present state obsolete by increasing in complexity until new support systems (more urbanization) are required.

As was pointed out in the section on Alternatives, there is little likelihood that steps will be taken to keep the area natural because there is little economic gain. And, even if this were possible, development would simply occur elsewhere with approximately the same incremental and synergistic effects. Notwithstanding some major socioeconomic event which could reverse the present growth trend of this boom-town area, the major alternative seems to be whether the area will undergo sprawl or planned development. The relative primary and secondary impacts have been discussed. The question remains as to which will have greater incremental and synergistic effects.

Given two development types, sprawl development might tend to develop only following support structures. However, the sudden development of a large "planned" area will require that a larger area of support be constructed. The planners may argue that they design in their own support systems but such is seldom the case; for example, at The Woodlands there are not sufficient jobs for those who will live in the new development. The conclusion here is that the planned community may not necessarily have less incremental effects than a sprawl community and may have even more. Planned communities will have less of an incremental effect only if all support systems are truly designed into them so that they do not stimulate the surrounding area to urbanize in order to support them. The Woodlands has not done this.

Synergistic effects would occur when two or more effects together have a greater total effect than the sum of the effects separately. The higher density of the planned development, together with the greater speed with which the development occurs, could produce a devastating synergistic effect. However, generally the ecological planning used by The Woodlands developers should result in fewer synergistic impacts than sprawl development, especially in the hydrology of the area.

IV. RECOMMENDED ALTERNATIVE

As is frequently the case in the real world, one is faced with choosing between the "lesser of the evils." The mind rebels against choosing unplanned sprawl over planned development but is equally leery of sanctioning a project which has very significant impacts on the environment and will almost certainly stimulate further development. Perhaps the solution is to allow a fairly independent team of experts to make the recommendation. They should have complete freedom to "live veto" individual parts of the proposed alternatives. Perhaps then they would choose the planned development but would insist that it occur over a longer period, utilize solar energy, and more mass transportation.

V. REQUIRED OPERATIONED ADJUSTMENTS

Presently, zoning laws and deed restrictions are not sufficient to insure that the promises of The Woodlands developer will even be carried out. The developer should give his proposals for carrying out this plan and legal consultants could give their opinion of the effectiveness of the proposals. If they are not effective, it should be realized that the planned development could very likely be worse than unplanned development, for it would have many of the same effects and would most likely stimulate a greater amount of supportive urbanization.

COST OF ENVIRONMENTAL ANALYSIS AND OF SPACE-TIME ANALYSIS

The cost of environmental analysis and planning at The Woodlands was divided into two parts: an initial study of $150,000 and a revised study of more than $250,000.

The total natural resource inventory and planning is about $3.2/person or $22.2./acre. The total planning cost (resource, economics, and social) including all staff costs was more than $3,000,000 or $24/person and approximately $167/acre. The additional costs of space-time analysis might well have increased the

TABLE 6-9. ENVIRONMENTAL IMPACT ASSESSMENT & PLANNING COSTS

Initial Ecological Study (aerial photos) from this was produced on Ecological Inventory		$ 80,000
Initial Ecological Plan & EIS on same (submitted to HUD)		70,000
Total Cost of Initial Work		**$150,000**
Revised Ecological Inventory:	Soils	$ 50,000
	Vegetation	14,500
	Land Planning	26,000
	Wildlife	60,300
	USGS gauging station (measures flow and quality)	19,000
	Total	169,800
Revised Ecological Plan		90,000
Total Cost of Revised Work		**$259.800**

cost / acre by $6.00 and the cost / person by $1.00. Significantly, space-time analysis uses the same resources that were developed in the ecological study and inventory. Thus, the ability to project ecosystem changes would be significantly improved by appropriate analysis.

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METHODOLOGY FOR SPACE-TIME ANALYSIS

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A number of methodologies have been proposed for use in preparing the environmental impact statements (EIS's) required by the National Environmental Policy Act (NEPA) of 1969. As reviewed by Warner and Preston (1974), these identify impacts through the use of maps (McHarg, 1969; Krauskopf and Bunde, 1972), checklists (Adkins and Burke, 1971; Institute of Ecology, 1971; Walton and Lewis, 1971; Dee and others, 1972; Smith, undated; Stover, 1972; Multiagency Task Force, 1972; and U.S. Army Corps of Engineers, 1972), matrices (Leopold and others, 1971; and Central New York Regional Planning and Development Board, 1972), and networks (Sorensen, 1971; Sorensen and Pepper, 1973; Moore and others, 1973; Dee and others, 1973).

Warner and Preston (1974, p. 1) state "There is no single 'best' methodology for environmental impact assessment." They suggest that an impact methodology should be selected on the basis of whether or not the analysis is to provide information or is to assist with decisions, the potential alternatives, the degree of public involvement anticipated, the resources available, the familiarity of the analyst with the methodology, the significance of the issue, and the administrative constraints imposed by the agencies involved. Analysis of the various methodologies available using these criteria provides no clear choice of methods for the analysis of the secondary effects of urbanization.

Armstrong (1972) thinks that an approach can be developed that uses the best components of each of the available methods; he calls this "Space Time Analysis." Frug *et al*. (1974) and Rowe *et al*. (1974) appear to have had some success in impact assessment using an approach which combines the resources of several methods. Dorney (1973) suggests the use of a team of experts or specialists may provide the best, quick, cheap and direct analysis of single effects. An appropriately selected team would provide the latest information and, group dynamics would provide the necessary systems analysis. In actuality, almost all methods used to date are tools to aid in conceptualization and presentation and do not provide significant analytical capability.

Biologists use two approaches to discovery: description and comparison. Description can be used to demonstrate association, function, organization, and interactions of the processes, materials, individuals, or system. The description can be in the form of a sentence, schematic, model, or computer information bank. Comparisons can be used to reveal the differences between cases or the stages in a time sequences. The scientific method uses observation and description to develop hypotheses which are tested by comparisons between cases (before and after, with and without, various amounts of treatment). Hypotheses which continuously and consistently predict the results are considered theories. Elements of both description and comparisons are required of a methodology which will project (provide hypotheses) about impacts.

Methodologies for impact assessment share certain common characteristics. To analyze an impact, they describe the project or program which represents the source of changes and the system or environment which will be perturbed or modified. This analysis is usually qualitative and often has many subjective elements when conscious or unconscious value judgement affect the selection or weighting of factors to be considered. However, measurements of causes and effects can make the analysis more quantitative while clear statements of assumptions can make it more open and objective.

The ideal methodology for impact assessment would be simple, reliable, and widely applicable. The "would be" is emphasized because no such methodology now exists and those which have been developed are only approximations of the ideal. Still, it is worthwhile keeping in mind the criteria for a perfect methodology when using existing methodologies or developing new ones. The desire to keep it simple may be the most difficult to achieve. Even a small-scale, short-term project can interact with environmental conditions, already subject to natural variations, in a multitude of ways. Perhaps a realistic definition of a simple methodology would be "one which does not require years of special training to master yet takes into consideration all the technology-environment interactions which are of importance in decision-making." Reliability is somewhat easier to specify and achieve. The methodology should give similar, if not identical, results each time it is used. It should also be reasonably unaffected by user bias, providing reproducible results when applied by individuals of diverse experience and interests. Finally, the methodology should be applicable in many different situations. This raises a problem familiar to anyone who has tried to sell a product. If it does one job very well, the product may have a limited market. The ideal product or methodology is one which does a variety of jobs reasonably well. For example, a methodology that can be used in the assessment of mining and construction impacts on terrestrial and aquatic ecosystems would be more valuable but less precise than one which covered only highway impacts on soil profiles and water tables.

GENERAL DESCRIPTION OF CHANGING ECOSYSTEMS

The overall purpose of the methodology is ultimately to describe changes in a particular set of ecological variables that result from urbanization induced by changes in population and increased infrastructure investments. The objective of the methodology must be to determine what the impacts will be and to express these findings in a form in which professionals can identify the confidence limits of the predictions,while also couching the predictions in terms in which the decision-maker (citizen or politician) can understand the implications of his decision. The methodology offered here should be construed by practitioner as an "overall approach," "a way to view your effort," and/or "as a source of formulating questions to which you will obtain much need answers."

Ecological variables are defined as those variables that best describe the state of the ecosystem at the time of description, that is, the existing state of the ecosystem, $\bar{E}$, of the prescribed area.

The methodology asserts that there are transforming forces T (population growth and public investments forces that when aggregated result in urbanization) which ultimately change the state of the ecosystem $\bar{E}$ to E_P.

Simply put, $\bar{E}$ - - - - T - - > E_P

where E_P is the predicted state of the ecosystem, described with the same variables that describe $\bar{E}$; E_P is assessed with respect to the time of impact of the specific project.

Consider:

$$\bar{E} \xrightarrow{T} E_P$$

I. - Describe $\bar{E}$, the existing state of the natural ecosystem that will be in the area where the secondary effects will impact:

II. - Conceptually, there are two distinct forces that comprise T:

T_1: The aggregated institutional forces, i.e., planning, economic, social, political,. . . etc., that monitor and induce urban growth. These will not be analyzed by this study.

T_2: The impacts generated from the induced urban growth that alter $\bar{E}$, the existing state of the natural ecosystem.

III. - Assume a monotonic increase in the generation of impacts for the commercial, residential, and recreational sectors. The impacts of the industrial sector will be region- and industry-specific. Together, these impacts will contribute to the inputs for the analysis of changes in the ecosystem.

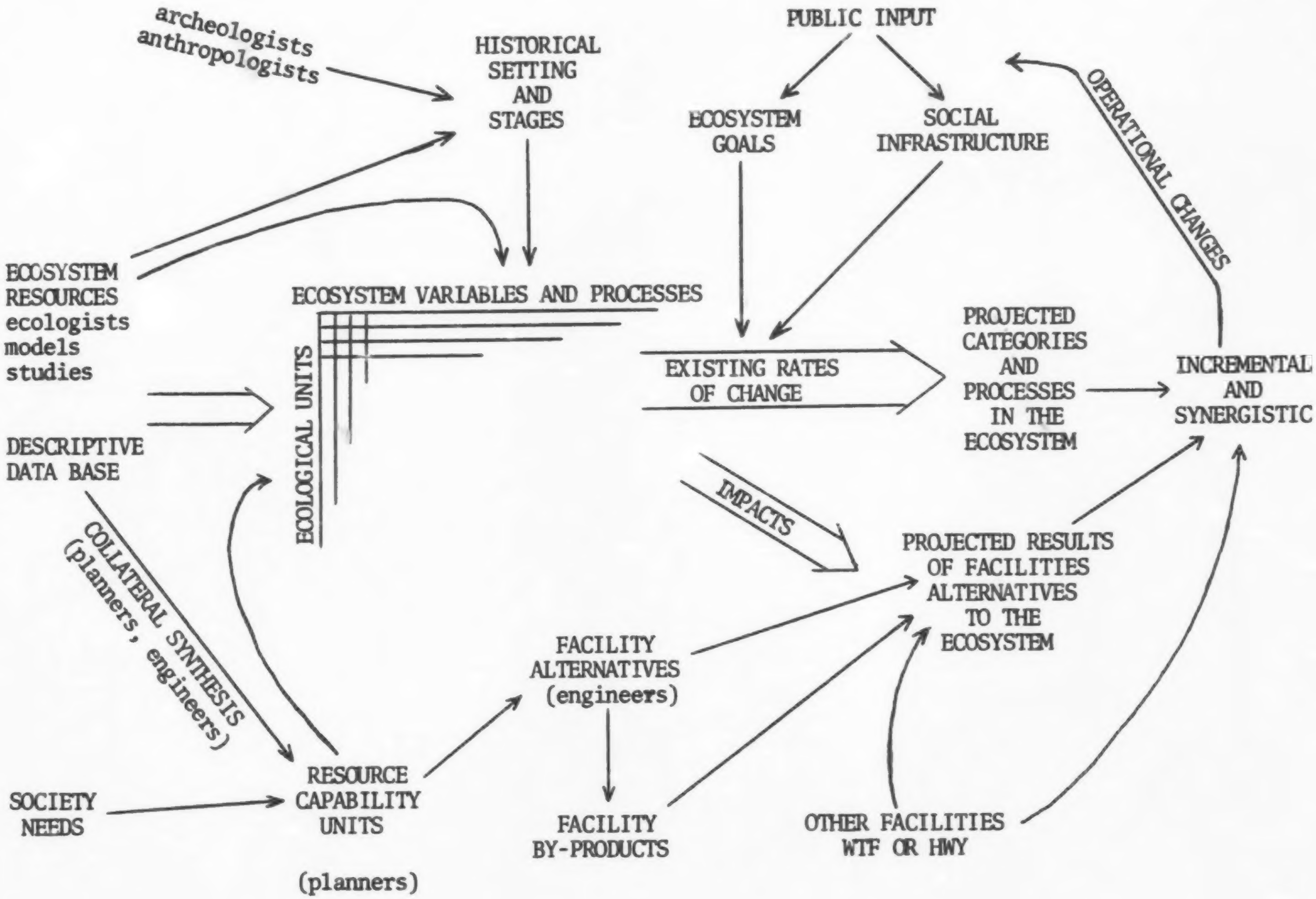
IV. - The results obtained through the use of the models will enable us to project the future state of the natural ecosystem, E_P.

The information obtained in utilizing this methodology that attempts to predict the state of the natural ecosystem is significant for the environmental impact statement writing and review process. In effect, the quality of our environment, in part, relies on the EIS process as an informational feedback loop. That is, the economic and political insitutions are not well designed to either collect or process this class of information. Consequently, the EIS procedure, in general, provides this information by institutionalizing a negative feedback loop.

SPACE-TIME ANALYSIS

The proposed Space-Time Analysis is designed to emphasize the dynamic nature of the ecosystem. Ecosystems are constantly changing, and often man's activities have the greatest impact by altering the rate of that change. The space over which the facility will have impact is identified and described in three dimensions, and the changes during time are indicated, including the case of no additional human intervention (null case) and each alternative intervention. Existing (on shelf) models, maps, data bases, regional plans, and a team of ecologists are used to identify ecological units and processes to best project, describe, and identify the potential environmental change. The description of the existing situation requires a consideration of the ecosystem structural characteristics, variables, and processes with particular emphasis on cyclic (seasonal) phenomena and on existing trends in the system. Each of the characteristics and processes undergo changes which can be projected because of already existing phenomena and because of actions which are already predictable, e.g., human population growth. The description of the several possible human interventions needs to include a comparison of the diverse results which are possible from these alternatives. The recommendation should follow logically from the above discussion but the summary should clearly indicate why the null case is not satisfactory. Almost any public investment, and particualrly

FIGURE 7-1. SPACE-TIME ANALYSIS


archeologists
anthropologists
HISTORICAL SETTING AND STAGES
PUBLIC INPUT
ECOSYSTEM GOALS
SOCIAL INFRASTRUCTURE
OPERATIONAL CHANGES
ECOSYSTEM RESOURCES ecologists models studies
ECOSYSTEM VARIABLES AND PROCESSES
ECOLOGICAL UNITS
EXISTING RATES OF CHANGE
PROJECTED CATEGORIES AND PROCESSES IN THE ECOSYSTEM
INCREMENTAL AND SYNERGISTIC
DESCRIPTIVE DATA BASE
IMPACTS
COLLATERAL SYNTHESIS (planners, engineers)
PROJECTED RESULTS OF FACILITIES ALTERNATIVES TO THE ECOSYSTEM
FACILITY ALTERNATIVES (engineers)
SOCIETY NEEDS
RESOURCE CAPABILITY UNITS
(planners)
FACILITY BY-PRODUCTS
OTHER FACILITIES WTF OR HWY

a wastewater treatment facility or a segment of a highway, makes an incremental contribution to impacts which may not be clearly evident from the impacts of the specific project itself. These incremental effects need clear identification. Additionally, it is most important to identify potential and assured synergistic effects which will result because of the interaction between various human interventions.

Purpose.- The purpose of the methodology is to provide an analysis of the direct impact of urbanization (i.e., the indirect or secondary impacts of public investments, e.g., Waste Treatment Facilities and Highways) on ecosystems and agricultural systems. Consulting specialists are assumed to have the requisite knowledge and experience with the local situation to identify the appropriate techniques.

The proposed Space-Time Analysis requires several general steps.

I. Description of the existing state including
   a. identification and location of ecological units and categories
   b. identification and characterization of the dynamic ecological processes
   c. description of the historical stages and setting
   d. identification of environmental icons, ecological goals, and the role of public participation
   e. projection and description of changes which will occur without additional human intervention (no action)

II. Description of each project alternative and its consequences

III. Description of incremental and synergistic effects accompanying each project alternative

IV. Recommendation of a specific action

V. Statement of required operational adjustments which result from the recommended project.

DESCRIPTION OF THE EXISTING STATE

Identification and location of ecological units and categories and of the dynamic ecological processes which exist at the present time in the region that may be impacted constitutes the information which has the largest documented data base and which is most familiar to the decision-maker and to the EIS writer. Descriptions of the historical stages and setting which are read prior to an understanding of the unities and processes under consideration lack meaning and lead to duplication of descriptive elements. The identification of the envirnomental elements that are important to the public are difficult to perceive in the absence of an overall initial description because, for example, a small hill in open plains might be more important than the same size hill in the midst of the Rockies. Thus, the logical order of goals, historical setting, units and processes, and projection, in the absence of the project has been modified by the realities of the descriptive process and particularly by the two case studies.

The description of the existing state must emphasize the dynamic nature of the ecosystem and provide special emphasis to the trends and cycles present. Some of the cycles are self-evident and include daily, seasonal, annual, and long term influences which result in movement of organisms, materials, and processes in the ecosystem. Two significant trends are always present: first, the orderly and often predictable events of biological succession and second, the imposed trends which result from the activities of man. Almost any descriptive tool can be used to present the changes which are occurring, but a most useful starting point needs to be the presentation of descriptions of the ecological units and the expectation of change from one unit to another. Thus, the following discussion provides an indication of some of the descriptive analytical tools and their usefulness to describe ecological units and to indicate the cycles and trends which occur and their ability to project future events.

DESCRIPTIVE DATA BASE

The descriptive data base for ecological analysis is limited only by the availability of time, money, and imaginative people. Even so, these limits do exist and all information is not equally useful. While almost any piece of information can become critical in a given situation, some information appears more likely to be of projective value in all cases. We can artificially group information into the broad categories of Resource Data and Human Use Data. From these data, we can identify units by the emphasis of criteria perceived to be important to a particular analysis. Resource Capability Units can be determined by the identification of the range of capabilities which land will support or the range of costs which are involved in using the land. Thus the cost of building skyscrapers on sand, of raising wheat in marshes, and of building houses on cliffs can be considered. Essentially the same data can be used to identify Ecological Units; the criteria emphasize the natural ecological process seasons and trends identifiable in the region under study. While Resource Capability Units are determined by emphasizing Human Use Data and Ecological Units are determined by emphasizing Resource Data, both analyses consider all available data. We will examine the descriptive data available and then examine some methods of analysis which can be used to determine Resource Capability Units and/or Ecological Units.

RESOURCE DATA

For our purposes Resource Data refer to climate, soil studies, hydrological studies, drainage patterns, aerial photos, satellite imagery, topographic maps, species composition studies (vegetation, wildlife, rare and endangered species), ecological studies (community analysis, ecosystem modeling, successional studies), and resource scholars with synthetic input not currently otherwise accessible.

Climate.- Climate data can be obtained in tabular or computer-processible form from the National Oceanographic and Atmospheric Administration for pertinent weather stations. Temperature, precipitation, turbulent storms, and fog are of particular interest because of the effects they have on the ecosystem and because of their susceptibility to influence by urban areas, Atkinson (1971). Adjacent weather stations can provide insights into the microclimate effects in an area, and, in the absence of the preferred on site micrometeorological studies, comparable data may be available from nearby biological or agricultural field stations.

Soils.- Soil maps are available from the U.S. Department of Agricultural Soil Conservation Service for most areas; many are accompanied by explanatory texts describing agricultural and construction potentials. State geological surveys frequently have helpful documents.

Hydrology and Geology.- Hydrology and groundwater hydrology data are often available from the U.S. Geological Survey. Particular attention should be paid to surface and groundwater flow records and to the distribution of recharge areas. Depths to the water table can be inferred from the soil map. Data on stream and lake chemistry may be available from previous EPA studies (such as the Lake Eutrophication study and the North American Project), the U.S. Geological Survey, state environmental and water development agencies, area colleges, and local conservation groups.

Aerial Photographs can be ordered from the Agricultural Stabilization and Conservation Service (for western states 2505 Parley's Way, Salt Lake City, Utah 84109, and for eastern states 45 South French Broad Ave., Asheville, North Carolina 28801). Most large cities have aerial services that will do specific jobs, and these may have recent aerial photos of the area of concern.

Topographic maps can be ordered from the Topographic Division, U.S. Geological Survey, Denver, Colorado 80225, or the Map Information Office, U.S. Geological Survey, Washington, D.C. 20242. Information on elevations, slopes, and topographic "grain" are easily obtained from U.S. Geological Survey topographic maps. Such information is important in understanding the pattern of microclimatic control on vegetation and wildlife and the disposition of corridors for future development and transportation of man.

Taken in conjunction with soil characteristics, the slopes indicate impediments to urban growth, which should be considered in the environmental analysis.

Satellite Imagery.- Multispectral scanners and cameras have been used by the Earth Resources program of the National Aeronautics and Space Administration. Information can be obtained from ERR Data Facility, NASA, Johnson Space Center, Houston, Texas 77058. Some material is available from state agencies and this is usually more accessible to the user. The satellite imagery suffers from missing data from cloud cover and because ground truth is the responsibility of the user, although he is unable to obtain prior information concerning the time of flights or the area to be studied. Spectral bandwidth from 0.5 to 12.6 microns have been divided into channels (usually 5) and these ranges result in the detection of various natural processes in a variety of colors.

Species composition studies.- These may be available from local universities, environmental groups, museums, state forestry, wildlife agencies, game warden, U.S. Fish and Wildlife service, and area naturalists. Both distribution and abundance are necessary to understand ecosystem processes but detailed on-site surveys have enormous resource requirements. Since plant and animal distributions are related to habitats, it may be possible to develop a sampling process which will identify a relatively small number of sampling sites that can be representative of the ecological variability in the region. Samples at different seasons of the year and over several years are required. In the absence of sufficient resources and time to do seasonal long-term studies, comparable data from studies at nearby field stations or ecological preserves may be helpful. Where these are lacking, short-term sampling processes supplemented by literature review and expert opinion will be necessary. The decision-maker needs to know that less than the best data are available and that expert opinion can attempt to identify the potential dangers which exist when decisions are made with these inadequate data.

The identification of rare and endangered species can be made by local experts and local environmental groups from their own studies and particularly from the recognized lists of these species.

Ecological modeling studies.- Access to these may be through local universities, from The Institute of Ecology (Box A, Logan, Utah 8432]), and from the various laboratories listed in the modeling section of this study or from those listed in Parker and Roop (1974). Ecological models available from engineers, state agencies, and consulting firms are often oriented to process application rather than to an understanding of ecosystem structure and function; to understand these processes, specialized models are most useful. Also see Kadlec, 1971 and O'Neill et. al., 1970.

Community and successional studies.- In general, these are available only from experts in the field working in nearby areas. These are studies which come closest to identifying the Ecological Units and the dynamic ecosystem processes on a site-specific basis. Communities are often identifiable by the local non-expert resident, and, when he is the decision-maker, provides him a comfortable approach. Successional studies identify the orderly processes of change which occur in ecosystems. Seasonal and long-term trends in ecological units can be recognized. The steps in these seasonal and trend processes are usually predictable and the causes of the change are often identifiable. Thus, for example, local ecologists know that one type of forest will be replaced by another forest unless human activities intervene. Some heuristic models have been used to identify the rate of transfer under natural conditions, and with human intervention.

HUMAN USE DATA

Data on human use of a region can be obtained from regional planning documents, economic reports, zoning ordinances, land use analyses, Forest Service maps, Agricultural Agency maps and reports, historical landmarks lists, public and private wildlife preserves and arboretums, Public Health Service reports, water pollution studies, air pollution studies, waste pollution studies, and transportation studies. Federal, state, and local government agencies provide access to these. On a regional basis, local councils of government often serve as clearing houses for these data. Description of the sources and utility of these data is outside the scope of this study but these documents, when available, often provide useful insights to ecological processes and methods of presenting results to decision makers.

ANALYSIS OF THE DESCRIPTIVE DATA BASE

Any locality has an existing set of ecological units which can be identified by terms familiar to the decision-maker. The analysis of the descriptive data base serves to identify and evaluate these ecological units and the ecological processes which characterize these units. The analysis can include simple table listings, multidimensional matrices, indices of distribution and abundance maps (often with overlays), flowcharts identifying relationships and processes, and complex multivariate processing requiring computer programs and advanced statistical procedures. The analysis of the descriptive data base needs to be made by a team of ecologists throughly familiar with the local ecological situation.

Tables and lists of data may be easy to obtain from regional data banks. These lists attempt to identify the various homogeneous attributes in the region. Data banks are not universal and when present they often contain abnormally large numbers of errors. Tedious analyses, encoding, and keypunching by individuals with no direct interest in the data take their toll. Therefore, all data should be filed, checked, and the result of the field checking at the site under consideration should constitute an integral part of the EIS made available to the decision-maker.

Given some general listing of the data available in the form of tables, one of two approaches can be made for further analysis. First, the area can be divided into grids and the environmental characteristics of each grid identified and stored in files or preferably on computers. Second, the data may be grouped into preliminary ecological units based on local experience and the environmental characteristics of each unit identified and stored. The first method is by far the most appealing scientifically but the second method may offer economies of time and funding. The second method may be particularly applicable when a second or third EIS is made in the same drainage basin by the same investigators. When the grid method is used, the determination of the size of the grid will often require compromises enforced by the various users of the data. The grid has spatial location on the site and all data can be collected and stored by grids (Murray et al., 1971).

With the data in computer processible form other multivariate procedures can be used to search for environmental relationships. These procedures can consider a number of co-occurring characteristics simultaneously and are useful to the impact analyst to quickly and objectively understand his data. A number of summaries of multivariate techniques exist: Sneath and Sokal (1975), Bryant and Atchley (1975), and Atchley and Bryant (1975) may be useful. A number of computer packages are available; perhaps the most widely distributed is that of Dixon (1968), although many of the desirable procedures are available in any of the packages. In general, multivariate analysis can be used to provide elegant descriptions of data and to discern and to describe interrelations between sets of data. These descriptions are not useful without understanding the underlying biological principles. The most comprehensive compilation of principles and techniques for the identification of ecological units is that of Whittaker (1973). The various ecological processes are best understood by reference to the ecosystem models described in a previous section.

Mapping.- Maps constitute one of the quickest and most easily understood means of presenting environmental unit data. Most data will already be available in map form. Programs are now generally available for the routine mapping of spatial data using computer facilities; all that is necessary is to have the data in machine-processible form, which is a requisite for most analyses.

Typically, maps have been used to describe *status quo* conditions. These include topography, soil type, vegetation, resource distribution, land use, etc. Maps are often based on extensive ground surveys and aerial photography, with some use of satellite imagery. *Sometimes* it is possible to identify unique combinations of historical and natural resources by using a set of overlay maps (McHarg, I., 1969). Master plans which project desired land use patterns for a county or region twenty-five or more years in the future typically fail to describe impacts.

Maps have the great virtue of literally giving the viewer a "big picture" and development can be seen in relation to existing features, natural or man-made. However, excessive or exclusive use of mapped information may confuse the eye and confound the issues. Additionally, mapped information reflects the adequacy of the original data; if it is precise, a resulting map may be useful. If the original data and poor, the map may be nearly useless as an analytical tool. Moreover mapped information tends to be static and does not reflect past, present, or future dynamics.

Diversity Indices.- The most notable attempts to combine the measures of species richness and evenness were made by Simpson, Shannon and Weiner and Brillouin. The simplest index, Simpson's C (Simpson, 1949), is based on the probability that two individuals randomly chosen from a population, without replacement, belong to the same species.

$$C = \sum_{j=1}^{s} \frac{n_j(n_j-1)}{N(N-1)}$$

where C is the diversity index, N is the total number of individuals in all species sampled, n_j is the number of individuals in the $_j$th species, s is the total number of species. This index is most appropriate if the relative degree of dominance of a few species is of more interest than the overall evenness.

Brillouin's H and Shannon-Weiner's H' (Shannon and Weiner, 1963) were derived from information theory and measure the uncertainty of predicting the species to which an individual drawn at random from the population belongs. Brillouin's H assumes all members of the community are identified and counted.

$$H = \frac{c}{N}(\log_{10}N! - \sum \log_{10}n_j!)$$

where c is a constant used to convert logarithms base 10 to the chosen base of measurement (c = 3.321928 for base 2 and c = 2.302585 for base e).

The Shannon-Weiner Index H' assumes a random sample from an infinitely large population and all of the species of the community are represented

$$H' = \sum_{j=1}^{s} p_j \log p_j$$

where $p_j = \frac{n_j}{N}$ or the proportion of the total number of individuals contained in the i^{th} species. These two information indices (H and H') are affected less by the extremely abundant or rare species than by the moderately abundant species.

Species diversity reduces many community measurements to a single number and consequently is liable to oversimplification. The combination of richness and evenness can result in ambiguity. High diversity results from a high number of species and an even distribution of individuals among species. An ecosystem with a large number of species and an uneven distribution could have the same total diversity as one with few species and even distribution. This problem has been alleviated by using indices of both species richness and evenness.

Species richness indices (d)

1) $d = S$ = number of species
2) $d = (S - 1)/\log N$ $\qquad$ N = total number of individuals
3) $d = S/\sqrt{N}$

Evenness index (e)

$e = H/H_{max} = \bar{H}/\log s$ $\qquad$ $\bar{H}$ = Shannon Index

$= \frac{1}{N} \log \frac{N!}{\{[N/S]!\}^{s-r}\{[(N/S)+1]!\}^{r}}$ $\qquad$ $r = N - S[N/S]$

Cluster analysis classifies the data into hierarchical groups on the basis of common patterns or similarities of the distributions of characteristics. The results are presented as dendrograms, with the level of branching indicating the level of similarity. Both cells and characteristics can be compared in this way. Thus, characteristics that tend to occur together can be identified including the obvious grouping of lake and lakeshore characteristics and the less obvious grouping of income-intensive horticulture, specialty farms, and light manufacturing with utility lines. Cells that are similar can also be identified, and, by means of a matrix presentation, they can be compared with the clusters of characteristics in order to understand the overall patterns of land use and/or ecosystems in the impact area. Therefore, cluster analysis can be a powerful tool, sharpening the analyst's perception of environmental classes.

Matrices.- Multidimensional aspects of the analysis can be presented in two dimensional-tables with the individual entries identifying more than one characteristic. Leopold (1971) used entries which provided a subjective rating of the magnitude of impact and the importance of the impact. These matrices are certainly useful as a preliminary exercise in ordering priorities.

Ordination is not as easily understood by most people. However, if the technique is mastered, it can be quite useful in the interpretation of environmental relationships (Bray and Curtis, 1957; Park, 1968, 1974; Hill, 1973). Using the same basis for computation of similarities as cluster analysis, points representing the cells can be arrayed in two-dimensional space on the basis of their dissimilarities to each other, and available information can be plotted in the resulting model of particular interest in principal component analysis.

If R = correlation matrix formed from the vector x_i of measures of atributes of ecological units of arbitrary grids
λ_i = the i^{th} eigenvalue
U = the i^{th} direction cosine eigenvector
I = identity matrix
then $(R - \lambda I) = 0$
and $(R - \lambda I)U_i = 0$
$U_i X_i = p$ = principal component score for the sample

Factor analytic methods allow rotation of axes to identify the correlation between factors. A number of modifications and applications of ordination techniques are available.

Discriminant Function Analysis.- Several discriminatory methods are available to provide a tool for maximizing the differences between samples. The relation between the sample differences and the predictor variables can be expressed as a linear discriminant function (Fisher, 1938). This method has great potential for objectively identifying areas of possible impact, given some knowledge of key environmental characteristics. As regional data banks grow and more experience is gained in the analysis of impacts, it should be possible to derive discriminant functions of general application.

Discriminant analysis has a long history of usage, and many programs are available. In all programs the sample characteristics are weighted in such a manner as to minimize the overlap between classes of samples (or cells of the previous examples). The weightings of characteristics are used in equations for determining the scores by which additional samples can be assigned to the respective classes. If the samples are classified on the basis of qualities or environmental impacts then the procedure can be used to identify areas subject to impact as in the hypothetical example.

When

q_{ik} = i^{th} quality measure of the k^{th} group.

W = within group variance covariance matrix

A = between group variance covariance matrix

λ_i & U_i = eigenvalue and eigenvector

U_i = discriminant coefficients

then

$$|W^{-1}A - \lambda_i I| = 0$$

$$(W^{-1}A - \lambda_i I)U = 0$$

and

$X._iU_i$ = discriminant score of the k^{th} water sample station

$\underline{V}_i = W_{ii}U_i$ = vector relating significance of the i^{th} measure to the discriminant function

λ_i magnitude tests statistical significance of discriminant function.

Canonical correlation analysis.- Variation between sets of variables can be approached by canonical correlation (Kendall and Stuart, 1966), which allows us to study the relation between the variation in the set of quality characteristics (chemicals, bacterial counts, flow, turbidity) and the set of predictors (weather, soil, vegetation, urbanization). Canonical correlation analysis is an exploratory tool, which provides an idea of the structure of the multivariate complex and gives us the maximum amount of correlation between linear functions of the groups of variables.

If R_{pp}= correlation matrix of predictor variables

R_{qq}= correlation matrix of quality variables

R_{pq}= intercorrelation matrix of quality and predictors

then

$$(R_{qq}^{-1}R_{pq}R_{pp}^{-1}R_{qp} - \lambda_i I)\ U_i = 0$$

The largest root, λ_i, is the square of maximum possible correlation between linear combinations of the two sets of measures, and the standardized U_i provide the correlations between the sets of variables.

Canonical correlation analysis is intuitively related to other multivariate procedures such as principle components, and indeed Glahn (1968) has demonstrated its relation to discriminant analysis and multiple regression.

Impact Flowcharts.- Many impacts are not amenable to modeling, but rather are best determined on the basis of the insights and experience of environmental specialists.

Impact flowcharts are practical aids to this type of intuitive analysis, both as an exercise in conceptualization and as a valuable means for presenting that conceptualization to decision-makers. They show qualitative relationships in a chronological perspective. Starting with a source event (construction of wastewater treatment facility or highway), a flowchart shows a logical sequence of cause and effect. Since one cause usually has multiple effects, branching occurs.

This form of presentation is particularly applicable in suggesting secondary impacts with all their ramifications. By using heavier lines, it is possible to emphasize differences in the magnitude of initial impacts or to show that secondary impacts may be greater than primary impacts; but these distinctions, unless based on actual measurements, will remain subjective. Perhaps the greatest value of a flowchart is that it can help identify sensitive areas and areas where environmental tradeoffs are involved. Once these are identified, the impact analyst can concentrate on obtaining more objective estimates of their response to anticipated changes.

One difficulty with this intuitive approach is that it does require a breadth of training in environmental sciences. To implement it, an in-house team representing terrestrial and aquatic biology, geology, environmental engineering, agronomy-soils, and planning is required.

Models.- Models are physical analogs or mathematical descriptions. They may be simple, elegant, precise, robust, general, sensitive, heuristic, complex; unfortunately, seldom more than a few of these characteristics fit a single model. Models are often used to assess the result of a particular action under conditions where assumptions can be made about the variables, the interactions between the variables, and the time over which the projections are required. Mostly models do small jobs very well; when they are large enough to do a comprehensive analysis, they often lack generality and precision. Experimental components systems analysis require "that the characteristics of any specific example of a complex process can be determined by the action and interaction of a number of discrete components" (Holling, 1965, p. 201). Large systems models,use computers for storage of data and of component mathematical models and the various parts are treated as separate compartments. This has provided for the development of precise models for the components of the Eastern Deciduous Forest Biome,while allowing considerable flexibility in developing the understanding of the overall interactions between the components (Reichle, 1975).

Ecological Units and Ecological Processes

The results of the analysis of the Resource Data should be the identification of the ecological units and the ecological processes which characterize each of those units. While it is easy to assume the position that each individual, or even each cell is a significant living unit and deserves consideration in an Environmental Impact Statement, it is clear that cells and individuals may have life spans several orders of magnitude less than the ecological units which characterize the ecosystem. Ecological units identify groups of individuals that interact together and have common ecological processes that can be measured and that are impacted by changes in environment. An integral component of the analysis of ecological units and ecological processes is an understanding of biotic diversity.

The simplest definition of biotic diversity is the number of different categories of biotic entities in an area. The categories may be growth forms, habitats, vertical strata of occurrence, community processes (variety of cycles and fluxes), or commonly, taxonomic groupings. Habitat diversity (heterogeneity, process diversity, complexity), and biotic diversity (total species numbers and evenness) contribute to the diversity of an ecosystem as well as to each other. Heterogeneity increases biotic diversity by making possible the coexistence of species with different adaptations and requirements. Furthermore, a complex web of processes is a logical consequence of many species sharing an ecosystem. Diversity thus has both static spatial and dynamic temporal elements.

A species population is assumed to fluctuate less widely in numbers in a diverse community. This diversity-stability link seems quite logical but it has been difficult to demonstrate in highly diverse communities. Diversity may contribute to "checks and balances" and it may provide buffering and redundancy, leading to greater stability at the population, community, and ecosystem level, but the contribution of diversity to homeostasis at any level is not easily measured.

Two factors cause one system to have a higher diversity than another: (1) more species (greater species richness), or (2) individuals which are more evenly distributed among the species (greater evenness). One system may have a greater species richness if (1) it is closer to an abundant supply of organisms which can successfully live in it, (2) its area is greater, (3) its mosaic of similar habitats is more dense, (4) its chemical environment is less stressful, (5) its climate is less variable or more predictable, (6) its ecosystem is biologically controlled, and (7) its physical diversity is greater. A system has great evenness if no one species is highly dominant. The combination of these two components is species diversity.

While the identification of ecological units and ecological processes is site-specific, certain commonalities will form the basis of any analysis. These are (1) succession, (2) trends and gradients, (3) productivity and energy flow, and (4) mineral cycling. Succession is the replacement of one community by another, often in an orderly and predictable sequence. The sequence may be initiated on bare rock or open water or on subtrates produced by human activity and should terminate in predictable communities. Human interventions may alter the rate of succession or even return it to step one (strip mining or formation of a new reservoir). Human interventions may also stimulate the rate of succession (reclamation, fertilizers). Succession is characterized by change in species structure, increase in biomass and organic matter accumulation, and a gradual balancing of community production and respiration. If the environment remains relatively constant, the species which inhabit an area will gradually modify it so that it is no longer favorable to their own survival. However, the environment is made favorable for another community or organisms. Eventually, a self-maintaining, usually long-lived, terminal community appears (climax community). This community will remain as long as the environment is free from disturbance.

Few communities are actually free from disturbance. In addition to natural perturbations, man disturbs natural systems with fire, harvesting natural production, and grazing wild and domestic stock. Perhaps most significantly, man has cleared large areas of natural vegetation and replaced it with simple, highly artificial communities of species adapted to grow on disturbed sites.

The terminal communities in a given area may be altered by major gradients and changes in the climate regime. Additionally, microclimatic and microenvironmental gradients result in changes in the rate of succession which can be measured and identified. Replacement of forest by agriculture, plains by cities, and rivers by large lakes result in microclimatic shifts which alter the predicted course and result of succession. The general trend of urbanization, agricultural expansion, and lake development can be measured and projected.

Man's modification of natural areas follows a succession-like format. Natural land is used for recreation, then for grazing, then for farming. Farmland near the city is often allowed to lay fallow a few years before residential suburban homes are built on it. Finally industrial and urban areas - the climax stage of human succession - appear. This succession is characterized by air and water pollution from industrial and domestic waste. Aquatic systems associated with urban systems are usually eutrophic.

One of the outstanding characteristics of natural communities is their dynamic nature. Man's systems can also evolve quickly into humanly more complex and biologically simpler systems. However, they revert to their natural state very slowly. Thus, both trend and gradient analysis become necessary components in the understanding of the role of human interventions on the ecosystem.

Most of the ecosystem processes are related to productivity, energy flow, and mineral cycling. Simple food chain relations illustrate and summarize complex trophic interactions. Models of ecosystem processes summarized in other sections can provide guidelines for understanding the site-specific characteristics of the identified ecological units. Clearly an understanding of the projected changes in productivity, energy flow, and mineral cycling of each ecological unit is necessary to understand the successional and long-term trends of the ecosystem and particularly to understand the significance of a particular human intervention.

Historical Framework

An identification of historical changes is necessary to an understanding of the additional impacts to be provided by current and future human activity. Few truly "natural" areas exist today in the contiguous United States - all have been affected to some degree by the activities of man. Previous ecosystem states and responses provide a clue to the continuing vulnerability and resiliency of an area. Much of North America has changed significantly since the maximum glacial advance and these changes are well documented in the paleoecological literature. Less well documented, but surely equally significant, are the impacts of the gathering, hunting, and agricultural activities of pre-European man. Somewhat better documented, if not better understood, are the changes European man produced. A summary of these historical changes contributes to an understanding of the additional impacts of current and future human activity. The historical consideration also requires a recognition of the natural cycles known to exist: seasonal, long-term cycles, and generally recognized successional trends. This preliminary statement assures that the decision-maker will be prepared to consider each affector and each changing variable in an appropriate time perspective.

Recent Changes in Ecological Units.- In order to predict the continuing changes that will occur without additional intervention, it is necessary to have some baseline data on recent rates of change in the amount of land occupied by the ecological units. The relationships of these rates to site-specific factors, such as soil types, slopes, and aesthetics need to be determined.

Fortunately, most areas of the country have data that were "captured" every few years and that are available for analysis of land-use trends. One data resource is in the form of aerial photographs (Hett, 1972).

With compatible time-series data in machine-processible form, it is possible to calculate yearly rates of change in land-use categories and to determine relationships to site-specific characteristics. Furthermore, computer-derived maps can be printed for each characteristic and time period, giving the analyst a "feel" for the dynamics, and the decision-maker an understanding of the impact of additional human intervention.

Determination of the space and time of impact.- For any impact statement to provide a tool for the decision-maker, the area to be impacted and the time of the impact need to be clearly identified. These are probably best done in relation to the historical setting, so that the projection of changes and particularly of rate of changes in the future have a basis for evaluation.

While the ecosystem is generally considered unbounded, to understand the structure and function at any time and place, some attempt to provide bounds is required. Distantly removed components will be less impacted than those close at hand but variations in value and stability may override first impressions. Value may lie in uniqueness, in providing an economic basis to human existence, or by providing ecosystem stability (a wilderness area, a commercial forest, a watertable). Even so, some ecosystem boundaries are required both with respect to space and time. With a Waste Treatment Facility, the distribution lines will identify the area where secondary development will be promoted, and the expected nature of this development will serve as an indicator of the type of urbanization expected. Additionally, this urbanization will provide impacts beyond the boundaries of the urbanization itself (e.g., agriculture and recreation areas).

Significant time units, those describing the time when rapid changes will take place (generally primary impacts) as well as the time during which little evident change will be expected, but during which potentially significant secondary impacts appear should be identified. During the years of initial and accelerated public infrastructure development, the most rapid changes are likely to occur in the land-use distribution of ecological units and in ecosystem parameters. The consideration of time must also include the ordinary life span of the facility, including replacement on-site and in kind and the effects which may remain after the facility is no longer functional as designed.

Environmental Goals

The environmental goals, with respect to the ecosystem, of the general human community will influence the recommended decision. Certainly the development of a Waste Treatment Facility in a busy harbor will require different goals than the development on a stream in a National Park. The statement of goals should identify each unique ecosystem unit ("icons") which exist in the area. The existence of state, regional, and local environmental plans and how well each provides an understanding of and protection for ecosystem structure and function should be indicated.

Adequate description of the area in terms of ecologic characteristics will facilitate the identification of environmentally sensitive areas and permit the consideration of specific environmental goals. Value may lie in uniqueness, in providing economic substructure to human existence, or by providing ecosystem stability (a wilderness area, a commercial forest, a watertable). The protection of nesting grounds, deer yards, and unique ecosystems from development is a valid goal under almost any circumstances. Likewise, the preservation of wetlands, stream banks, sand plains (including farms), and steep shorelines critical to the functioning of the ecosystem is of definite merit. Trained environmentalists should have little difficulty in identifying these areas.

Public parks and other environmentally-oriented recreation areas should not be degraded by permitting high-density developments and highways in proximity. By the same token, protection should be given to sites of historical or archaeological interest.

Identification of scenic vistas and other aesthetic characteristics is a little more difficult. Value judgment should take into consideration the environmental perception of the local residents. As a practical matter, decision-makers are more likely to support a particular course of action if the populace is known to be sympathetic toward the environmental goal.

Questionnaires can be used to determine public opinion. The simplest forms do nothing more than document general attitudes. More elegant forms can yield detailed information on the relationship of regional economics and lifestyles to environmental amenities but may be less satisfactory because of sampling costs and analysis complexities.

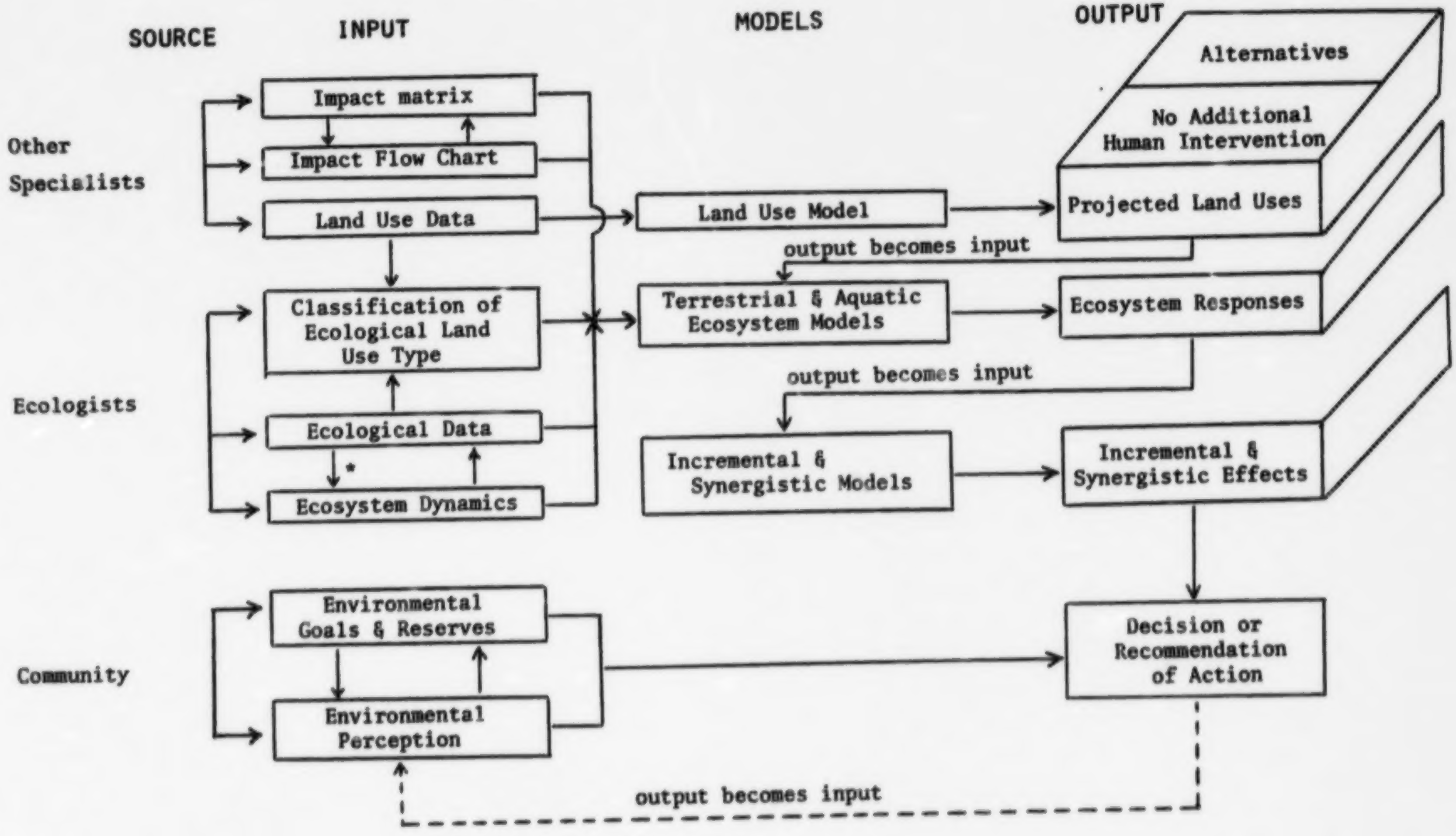
Environmental perception of recreationists, cottage- and homeowners, and businessmen has been extensively studied in many resort areas (Kooyoomjian, 1974; Kooyoomjian and Clesceri, 1974).

Projections of Changes Without Additional Human Intervention

Given an adequate identification of ecological units and ecological processes, and an understanding of the historical trends and the perceived environmental goals, the projection of ecosystem changes requires the development of a systematic analytical approach. One such approach is shown in the figure where a variety of inputs are used to drive ecosystem models that result in output projections of ecological land use, ecosystem responses, and incremental and synergistic effects.

Ecological land use models can be used to develop transfer matrices which will project changes in the distribution and abundance of some of the ecological units (Hett, 1971; Carlisle and Park, 1975). Land development consultants can identify the most probable type of development likely to occur in a specific site and can point out areas of comparable development. A new housing development served by a particular WTF or highway will be designed and will function much like other developments already in the area. Engineers can project some of changes in the amount and location of the chemical and physical characteristics of

FIGURE 7-2. ANALYSIS OF EXISTING TRENDS USING ECOSYSTEM MODELS


SOURCE
INPUT
MODELS
OUTPUT
Other Specialists
Impact matrix
Impact Flow Chart
Land Use Data
Ecologists
Classification of Ecological Land Use Type
Ecological Data
*
Ecosystem Dynamics
Community
Environmental Goals & Reserves
Environmental Perception
Land Use Model
output becomes input
Terrestrial & Aquatic Ecosystem Models
output becomes input
Incremental & Synergistic Models
Alternatives
No Additional Human Intervention
Projected Land Uses
Ecosystem Responses
Incremental & Synergistic Effects
Decision or Recommendation of Action
output becomes input

*note implied use of successional model

water, soil, and air, and changes in weather patterns, which will result from the presence of these housing, commercial, or industrial developments. Additionally, changes in the chemical and physical constitution of nearby lakes and streams can be projected (but with still less accuracy), and these chemical and physical changes can constitute inputs to the ecosystem models,

If an area is currently served by septic tanks or by an inadequate WTF, the ecosystem may be changed by the growth and development which will occur whether or not adequate WTF service is provided. Abandoned agricultural land in any area goes through a process of succession which may be projected by identifying and studying fields of comparable slope and exposure that have been abandoned for various periods of time. Lakes and ponds in an area change at rates that can be identified from ecosystem models and by examination of other lakes and ponds of known age and comparable conditions. As a nearby city expands, the diversity of plants and animals changes as a result of human activity outside and within the impacted area. For land use by each ecological type, the decision-maker needs to be able to identify the changes which would occur during the useful life of the infrastructure even if the facility is not constructed.

Other forces that change the ecosystem and produce long-term cycles and trends in the values of the ecosystem variables need to be identified. Natural forces include succession and seasonal changes. Existing sources of human intervention and their effect should be identified.

Perhaps the most useful approach for the decision-maker would be to identify for each ecological unit a comparable area which the decision-maker can visit to understand the projected situation. Each ecosystem variable that will be changed in each ecological unit needs to be identified, and projections of the amount and timing of these changes need to be described. Comparison of the current values (and the variability of those variables in existing situations) of comparable development stages may be useful in presenting the changes to the decision-maker. Presentation of these ecological units and projected changes can be by sequential maps or by maps with overlays. The maps should emphasize those seasonal, successional, and long term trend characteristics which are most sensitive to change. The categorization of ecological units should emphasize ecosystem in addition to human activity. One available method is described by Dansereau (1974), but local specialists can provide comparable schemes.

Some factors will probably be known to have an effect on the ecosystem, but the amount and ultimate consequences of that effect may be indeterminate. These factors should be identified and possible boundaries placed on their contribution to changing the ecosystem. It will be difficult to identify all of the forces of change; however, the decision-maker needs to know what proportion of the changes are likely to be the result of unidentifiable sources. Finally, the decision-maker needs to understand when the situation may change in entirely new and unpredictable ways.

In summary, a team of ecologists should be charged to:

1. Develop a comprehensive checklist of the potentially available and needed information to determine the ecological units and the ecosystem structure and functions. Ecological goals, environmental preserves, parks, endangered species, and the historical stages and setting should be indicated by sociological, paleontological and archaelogical studies. The list should be regional and site specific.

2. Identify the natural forces producing change including succession and seasons (trends and cycles) in the variables: 1) ecosystem variables and processes, 2) existing sources of human interventions, 3) unknown consequences of various indentifiable factors and 4) variability of unidentified source.

3. Where possible, identify the organic and non-toxic assimilative capacities of various ecosystem units for each substance with particular emphasis on federal, state or local laws, standards and regulations.

4. Determine the models, the processes and variables which should be available and appear to explain the observable rates of change in the ecosystem with particular emphasis on seasonal successional and trend changes. Determine the models to be used, the cost of computer runs, the driving variables to be used and the range of expected results.

5. Examine the available data and determine whether or not the resolution, (e.g. grid size), precision, variability and consistency is adequate.

6. Determine whether or not the data actually available is likely to be sufficient to make necessary projections in changes of amount of ecological categories, variable values and process rates. Is all the data necessary? Considerable effort should be made to reduce the original checklist to a small necessary and sufficient set of characteristics.

7. Determine what new data is needed and estimate both the cost and likelihood of obtaining that data.

8. Develop ad hoc analyses appropriate to the site specific special conditions.

9. Perform the necessary analyses to describe the existing dynamic aspects of the ecosystem with particular emphasis on the projection of the change which will occur without additional human intervention.

CHANGES ACCOMPANYING EACH PROJECT ALTERNATIVE

For any facility there are a number of alternative locations and for each there are a number of potential development patterns that can result. Since the urban development pattern may have greater and more long term impacts than the proposed facility on the ecological land use patterns and thus on the ecosystem parameters, these possible development patterns need to be emphasized in the description.

Land development consultants can identify the most probable type of development likely to occur in a given area and can point out comparable already developed areas nearby. Engineers can project some of the changes in the amount and location of the chemical and physical characteristics of water, soil and air and changes in weather patterns, which will result from the presence of these housing, commercial or industrial developments. Additionally, changes in the chemical and physical constitution of nearby lakes and streams can be projected (but with still less accuracy).

For example, implementation of the models for land-use changes and ecosystem structure and function patterns, and consequent effects on the terrestrial and aquatic ecosystems, is relatively straightforward. Construction of a WTF would remove the restriction placed on housing development by soils that are unsuitable for septic systems, allowing the removal of the site-specific soil reduction term and thus greatly increasing the probability of development in certain areas. Because of the component nature of ecosystem models, their linkage is limited only by the inventiveness of the scientist and the structure of the ecosystem.

DESCRIPTION OF THE INCREMENTAL AND SYNERGISTIC EFFECTS

The most difficult aspect of the measurement of the impacts of urbanization are those which relate to the accumulative effect of regional urbanization. While it is easy to see that most of the world is not urbanized, it is not easy to measure that urban populations are massive consumer units for the products of the extensive agricultural forest, and range land. Thus, land converted from agricultural to urban uses will require increased technological efficiency of the remaining agricultural land or will require more land to be converted from natural to agricultural land to support that urbanized area. The land remaining for new agricultural development is often marginal and requires increased capital investment and higher maintenance cost.

Since WTF and highways do not really stand alone but tend to accumulate in pockets along corridors, streams, or lakes, they tend to result in development patterns (urbanizations) along these corridors. Each forest, lake, stream, river, or estuary assimilates some organic and non-toxic material and energy from surrounding air, water, or soil. This material and energy is built into trees, grass, or algae which is in turn transformed into insects, birds, fish, and other creatures. Presumably the more individuals and the more species of plants and animals present in an ares, the more material and energy they will be able to absorb without significantly changing the nature of the ecosystem. The monocultures typical of cropland will absorb only a small portion of that which is absorbed by rangeland, and overgrazed areas will absorb far less than well-managed areas.

Clearly, all the surface of the earth cannot become a city because the city depends on the surrounding ecosystem. A critical question to ask is how much of the ecosystem can be replaced by city and still provide sufficient available biological productivity to support that city. There are two answers: the ultimate answer which is delineated by the capacities of the ecosystem itself, and the technological answer which is constrained by the ability of man to make those resources available. Being able to express an ultimate boundary in terms convincing to those who are buffered from the influences of the feedback from limiting or reduced available resources is not an easy task.

This study suggests the necessity of considering that the incremental effect of continued urbanization in a single area may overtax the available productivity of that area. This would increase the technological requirements to import resources from and export wastes to greater distances. In such a case, the recommended course of action should result in preservation of that ecosystem even if this requires the selection of a no action (non-construction of infrastructure facilities) alternative, which, in turn, precludes further urbanization.

Synergistic effects are even more complex to determine. Almost any process can interact with almost any other process to produce effects larger or smaller than would be predicted by the separate measurement of the two processes. Will two wastewater treatment facilities on opposite sides of a stream result in development patterns so different that the two street runoffs will mix to produce greater effects than would be predicted from either project? Experience suggests that this will happen and that we will probably not be able to identify it beforehand, but the EIS analyst should seriously examine the possibility and be sure that the decision-maker is informed of the potential hazards.

Clearly some overview which assures basinwide (nation wide) consideration of the consequences of each additional WTF or HWY is required. Any EIS that fails to determine the presence and absence of these institutional structures and their strengths and weaknesses has failed to provide the decision maker (ultimately the public) with an adequate consideration of the consequences to the ecosystem of the facility. Any approach which places the engineer or the ecologist in the position of informing the decision maker of how much the water or air will change with the addition of one more infrastructure investment will fail to provide any environmental protection. The methodology must provide for a consideration of all facilities which will be required to respond to human population growth and development in the basin.

Both incremental and synergistic effects are difficult to determine. This suggests the necessity of developing a reasonable basin wide monitoring program designed to provide early warning identification of problems. The funding of the monitoring investigative and development program should be included in the individual facilities or the EIS should clearly state that no funding is provided. The potential consequences of the absence of a monitoring program should be clearly delineated.

DESCRIPTION OF THE RECOMMENDED ACTION

The recommended action of an EIS uses the sum of all social, economic, and environmental factors. The conclusion reached by the ecological analysis may differ from that reached by the planner or engineer. The conclusion of the planner may be constrained by short-term economic values, while the conclusion of the ecologist may emphasize the long-term viability of the ecosystem. The decision-maker needs to be able to identify the ecological cost of the Environmental Impact Statement's recommended action.

REQUIRED OPERATIONAL ADJUSTMENTS

Once there is a recommended action, a number of unanswered questions will remain. The facility will provide for a given capacity. Mechanisms will be required to assure that urbanization is not more than projected and that the facility is not overtaxed. Some legislative adjustment will be required or the necessary feedback between ecosystem and urbanization will not be achieved. If these legislative adjustments are not provided, the consequences (impacts) need to be expressly stated for the decision-maker. Often societal structures impose actions which depend on the development of new technologies; when these technologies are lacking or their development is delayed, the impacts may be considerable. Incremental and synergistic effects are very difficult to predict; a monitoring system may provide an early warning mechanism to protect the public and the environment. The cost of a monitoring system needs to be included in the design of the facility.

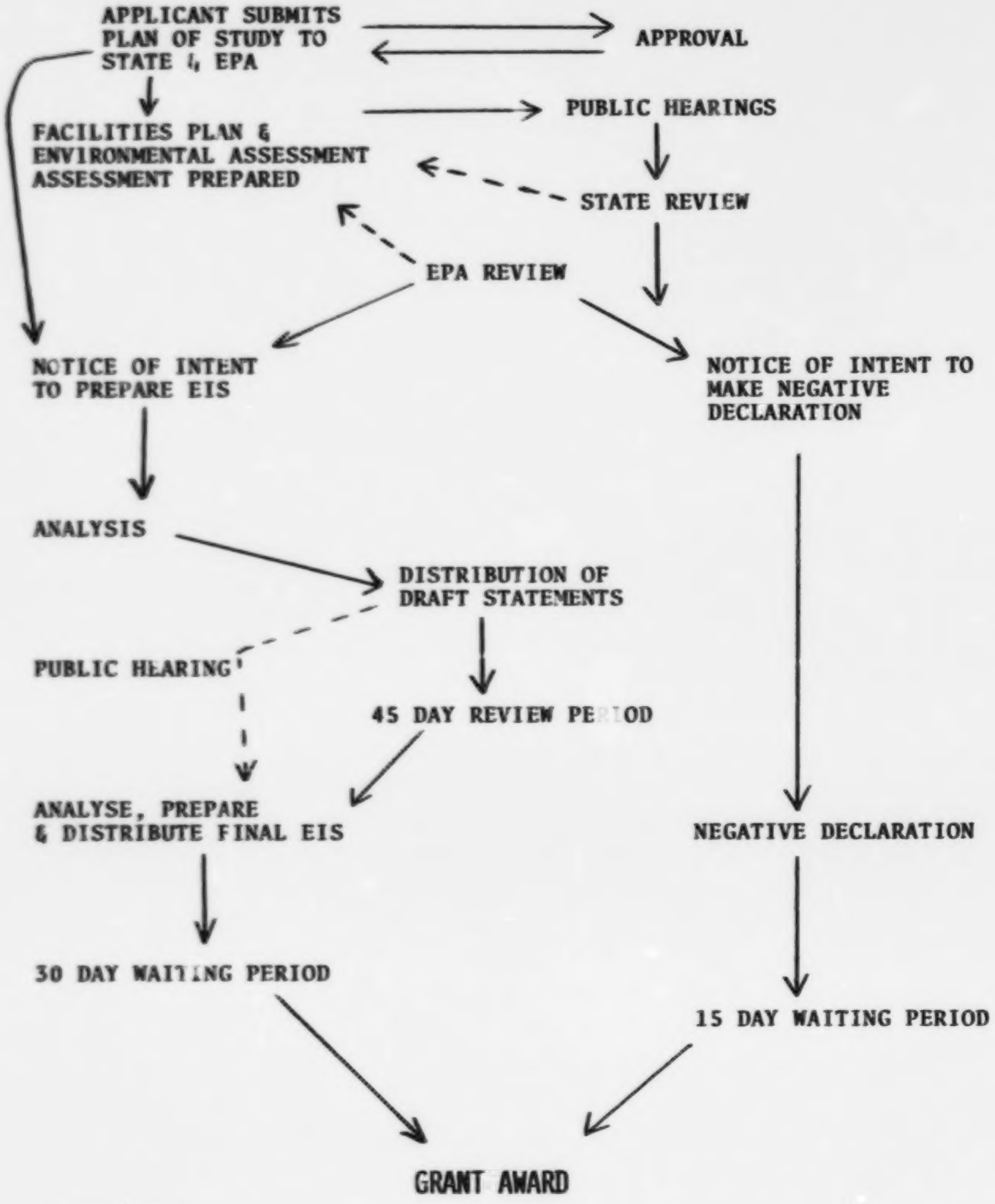
SPACE-TIME ANALYSIS AND THE PLANNING PROCESS

Section 201 and 208, Federal Water Pollution Control Act Amendments of 1972, require facilities and areawide planning, respectively. The generalized 201 process is shown on the accompanying figure. Space-Time Analysis is appropriate to the Environmental Assessment Preparation and should be indicated as an integral part of the plan of study proposed to state agencies and the EPA. The results from Space-Time Analysis can serve as the basis for a negative declaration or as the basis for the preparation of the final EIS.

Space-Time Analysis is particularly appropriate for the areawide planning process because of its emphasis on the dynamic aspects of an already changing environment and because the process will lead to an examination of the incremental and synergistic relations which are likely to accompany areawide development.

Space-Time Analysis is compatible with "Guidelines for areawide waste treatment management planning" and "Guidance for preparing a facility plan." For both facility planning and for

FIGURE 7-3. GENERALIZED 201 PROCESS


APPLICANT SUBMITS PLAN OF STUDY TO STATE & EPA
APPROVAL
PUBLIC HEARINGS
FACILITIES PLAN & ENVIRONMENTAL ASSESSMENT ASSESSMENT PREPARED
STATE REVIEW
EPA REVIEW
NOTICE OF INTENT TO PREPARE EIS
NOTICE OF INTENT TO MAKE NEGATIVE DECLARATION
ANALYSIS
DISTRIBUTION OF DRAFT STATEMENTS
PUBLIC HEARING
45 DAY REVIEW PERIOD
ANALYSE, PREPARE & DISTRIBUTE FINAL EIS
NEGATIVE DECLARATION
30 DAY WAITING PERIOD
15 DAY WAITING PERIOD
GRANT AWARD

---optional

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GLOSSARY

Adopted from: An Ecological Glossary for engineers and resource managers. The Institute of Ecology.

ADAPTATION - The result of process of long-term evolutionary adjustment of a population to environmental changes.

ALGAE - Any of a group of chiefly marine or freshwater chlorophyll-bearing aquatic plants with no true leaves, stems or roots. Ranging from microscopic single-cell organisms or colonies (ponduceds) to large macroscopic seaweeds, etc.

ALGAL BLOOM - Rapid and flourishing growth of algae.

ANAEROBIC - Capable of living or active in the absence of air or free oxygen.

ANNUAL - Pertaining to yearly occurrence.

ANNUAL INCREMENT - That which is added or gained in one year.

ANOXIC - Pertaining to conditions of oxygen deficiency.

AQUACULTURE - Production of food from managed aquatic systems.

ASSIMILATION - Transformation of absorbed nutrients into body substances.

ASSOCIATION - A definite or characteristic assemblage of plants living together in an area essentially uniform in environmental conditions; any ecological unit of more than one species.

BATHYAL - Of/ lake or ocean bottoms of very deep water, e.g. below 300 meters in a lake or below 5000 m. in the sea.

BENTHIC - Of/ the bottom of lakes or oceans. Of/ organisms which live on the bottom of water bodies.

BENTHOS - Those organisms which live on the bottom of a body of water.

BIOLOGICAL DIVERSITY - The number of kinds of organisms per unit area or volume; the richness of species in a given area.

BIOCHEMICAL OXYGEN DEMAND - The amount of oxygen required to decompose (oxidize) a given amount of organic compounds to simple, stable substances.

BIOMASS - The total weight of matter incorporated into (living and dead) organisms.

BIOME - Any of the major terrestrial ecosystems of the world such as tundra, deciduous forest, desert, taiga, etc.

CARRYING CAPACITY - The maximum population size of a given species in an area beyond which no significant increase can occur without damage occurring to the area and to the species.

CLIMATE - The average conditions of the weather over a number of years; macroclimate is the climate representative of relatively large area; microclimate is the climate of a small area, particularly that of the living space of a certain species, group or community.

CLIMAX - The final, stable community in an ecological succession (q.v.) which is able to reproduce itself indefinitely under existing conditions.

CLIMAX COMMUNITY - see climax.

CODOMINANT - Any of equally dominant forms; one of several species which dominant a community, no one to the exclusion of the others.

COMMUNITY - All of the plants and animals in an area or volume; a complex association usually containing both animals and plants.

COMMUNITY METABOLISM - The combined metabolism (metabolic activity) of all organisms in a given area or community.

COMMUNITY RESPIRATION - The combined respiration of all organisms in a community.

CONIFER - Pines, cedars, hemlocks, etc; any of a type of (mostly) evergreen trees and shrubs with (botanically) true cones.

CONSUMER - An organisms that consumes another.

CONSUMER (PRIMARY) - An organism which consumes green plants.

CONSUMER (SECONDARY) - An organism which consumes a primary consumer. (q.v.)

DECIDUOUS - Falling off or actively shed at maturity or at certain seasons.

DECOMPOSERS - Those organisms, usually bacteria (q.v.) or fungi, which participate in the breakdown of large molecules associated with organisms. Hence, those organisms which recycle dead organisms.

DENTRIFICATION - Chemical conversion of nitrates to molecular (gaseous) nitrogen (N_2) or to nitrous oxide or to ammonia by bacteria or by lightning.

DISSOLVED OXYGEN - An amount of gaseous oxygen dissolved in volume of water.

DIVERSITY - see, biological diversity.

DOMINANCE - The degree of influence (usually inferred from the amount of area covered) that a species exerts over a community.

DOMINANT - An organism that controls the habitat at any stage of development; in practice the organism that is most conspicuous and covers the most area.

DYNAMIC EQUILIBRIUM - A state of relative balance between forces or processe having opposite effects.

ECOLOGY - The study of the interrelationships of organisms with and within their environment.

ECOSYSTEM - A community and its (living and nonliving) environment considered collectively; the fundamental unit in ecology. May be quite small, as the ecosystem of one-celled plants, in a drop of water, or indefinitely large, as in the grassland ecosystem.

ECOSYSTEM ANALYSIS - Examination of structure, function and control mechanisms present and operating in an ecosystem.

EFFICIENCY (ECOLOGICAL) - Defined exchange of energy and /or nutrients between trophic (q.v.) levels; us. the ratio between production (q.v.) of one level and that of a lower level in the same food chain (q.v.).

ENERGY (ECOLOGY) - Most commonly, that portion of the visible solar radiation (light) captured by plants and ultimately used for food by the animals in an ecosystem.

ENERGY BUDGET - A quantitative account sheet of inputs, transformations, and outputs of energy in an ecosystem. May apply to the long-wave radiation (heat) of an organism or a lake, or to the food taken in and subsequently reduced to heat by an individual or a population.

ENERGY CYCLING - (Although this term is sometimes used to imply that the ecological energy in an ecosystem is reused, the term is incorrect.) Use instead, energy flow. (see below)

ENERGY FLOW - The one-way passage of energy (largely chemical) through the system, entering via photosynthesis, being exchanged through feeding interactions, and at each stage, being reduced to heat.

ENERGY TRANSFER PROCESS - Any process which transfers energy from one component in an ecosystem to another. Photosynthesis, feeding, bacterial break-down are examples.

ENVIRONMENT - The sum total or the resultant of all the external conditions which act upon an organism.

ENVIRONMENTAL AMENITIES - Attractive or esthetically pleasing environments or portions of environments.

ENVIRONMENTAL STRESS - Perturbations likely to cause observable changes in ecosystems; usually departures from normal or optimum.

ENVIRONMENTALIST - One concerned about the environment.

ESTUARINE - Of/ the mouth region of a river that is affected by tides.

EXCRETION - Elimination of waste material from the body of an organism.

FAUNA - The animals of a given region taken collectively; as in the taxonomic sense, the species, or kinds, of animals in a region.

FEEDBACK - Principle of information returning to sender or to input channel, thus affecting output.

FLORA - Plants; organisms of the plant kingdom; specifically, the plants growing in a geographic area, as the Flora of Illinois.

FLORA (MICRO) - Usually bacteria or fungi.

FOOD CHAIN - Animals linked together by food and all dependent, in the long run, on plants.

GREENBELT - A plot of vegetated land separating or surrounding areas of intensive residential or industrial use and devoted to recreation or park uses.

GRADIENT - A more or less continuous change of some property in space. Gradients of environmental properties are ordinarily reflected in gradients of biota.

HABITAT - The environment, us. the natural environment in which a population of plants or animals occurs.

HERBACEOUS - Of/ any plant lacking woody tissue in which the leaves and stem fall to ground level during freezing or drying weather.

HOMEOSTASIS - The inherent stability or self-regulation of a biological system; the ability of such a system to resist external changes.

JARGON - The other fellow's everyday vocabulary.

LAKE - A large body of water contained in a depression of the earth's surface and supplied from drainage of a larger area. Locally may be called a pond.

LAKE TURNOVER - The complete top-to-bottom circulation of water in a lake which occurs when the density of the surface water is the same or slightly greater than that at the lake bottom; most temperate zone lakes circulate in Spring and again in Fall.

LENTIC - Of/ still or slowly flowing water situations (e.g., lakes, ponds, swamps).

LIFE CYCLE or LIFE HISTORY - The series of changes or stages undergone by an organism from fertilization, birth or hatching to reproduction of the next generation.

LIMITING FACTOR - An environmental factor (or factors) which limits the distribution and/or abundance of an organism or its population, i.e., the factor which is closest to the physiological limits of tolerance of that organism.

LIMNOLOGY - The study of the biological, chemical, and physical features of inland waters.

MARSH - A tract of low-lying soft, wet land, commonly covered (sometimes seasonally) entirely or partially with water; a swamp dominated by grasses or grass-like vegetation.

MICROCLIMATE - Conditions of moisture, temperature, etc., as influenced by the topography, vegetation, and the like. See, climate.

NATURAL AREA - An area in which natural processes predominate, fluctuations in numbers of organisms are allowed free play and human intervention is minimal.

NATURAL ENVIRONMENT - The complex of atmospheric, geological and biological characteristics found in an area in the absence of artifacts or influences of a well developed technological, human culture; an environment in which human impact is not controlling, or significantly greater than that of other animals.

NICHE - The range of sets of environmental conditions which an organism's behavioral morphological and physiological adaptations enable it to occupy; the role an organism plays in the functioning of a natural system, in contrast to habitat.

NITRIFICATION - A step in the nitrogen cycle technically involving oxidation of nitrogen, e.g. NH_3 from ammonia to nitrates (NO_3).

NUTRIENTS - Chemical elements essential to life. Macronutrients are those of major importance required in relatively large quantities (C, H, O, N, S, and P); micronutrients are also important but required in smaller quantities (Fe, Mo).

OVERTURN - The complete circulation or mixing of the upper and lower waters of a lake when the temperatures (and densities) are similar.

PLANKTON - Small organisms (animals, plants or microbes) passively floating in water; macroplankton are relatively large (1.0 mm to 1.0 cm); mesoplankton of intermediate size; microplankton are small.

PLANKTON MERO - Organisms with temporary plankton phases in their life cycle, e.g., oyster and crab larvae.

POLLUTION - An undesirable change in atmospheric, land or water conditions harmfully affecting the material or aesthetic attributes of the environment.

POPULATION - A group of organisms of the sam species.

PRISTINE STATE - A state of nature without human effect or with negligible human effect.

PRODUCER = PRODUCER ORGANISM - An organism which can synthesize organic material using inorganic materials and an external energy source (light or chemical). See *autotroph*; also, *biotic pyramid*.

PRODUCTION - The amount of organic material produced by biological activity in an area or volume.

PRODUCTIVITY - The rate of production of organic matter produced by biological activity in an area or volume. (e.g.: grams per square meter per day, or other units of weight or energy per area or volume and time).

PRODUCTIVITY, GROSS PRIMARY - The rate of synthesis of organic material produced by photosynthesis (or chemosynthesis), including that which is used up in respiration by the producer organism.

PRODUCTIVITY, NET PRIMARY - The rate of accumulation of organic material in plant tissues. Gross primary productivity less respiratory utilization by the producer organism.

PRODUCTIVITY, SECONDARY - The rate of production of organic materials by consumer organisms (animals) which eat plants (which are the primary producers).

REMOTE SENSING - A method for determining the characteristics of an object, organism or community from afar.

RESILIENCE - The ability of any system, e.g., an *ecosystem*, to resist or to recover from *stress*.

SALINITY WEDGE - The movement of subsurface saline water into an aquifer, or, in an estuary. Of a body of saline (sea) water under the fresh water.

SOIL PROFILE - The physical and chemical features of the soil imagined or seen in vertical section from its surface to the point at which the characteristics of the parent rock are not modified by surface weathering or soil processes.

SPECIES COMPOSITION - Referring to the kinds and numbers of species occupying an area.

SPECIES DIVERSITY - Refers to the number of species or other kinds in an area, and, for purposes of quantification, to their relative abundance as well.

SPECIES DIVERSITY INDEX - Any of several mathematical indices which express in one term the number of kinds of species and the relative numbers of each in an area.

STABILITY (ecological) - The tendency of systems, especially ecosystems, to persist, relatively unchanged, through time; also persistence of a component of a system; the inverse of its turnover time.

STANDING CROP - The biological mass (biomass) of certain or all living organisms of an area or volume at some specific time, i.e., what could be harvested.

SUBCLIMAX - A stage in a community's development, i.e., succession (q.v.) before its final (climax) stage; a community simulating climax because of its further development being inhibited by some disturbing factor (e.g., fire, poor soil).

SUBLITTORAL - Below the lake or seashore; of/ the area between the low tide mark and (say) 20 fathoms.

SUCCESSION - The replacement of one community by another; the definition includes the (controversial or hypothetical) possibility of "retrograde" succession.

SUCCESSION, PLANT - The replacement of one kind of plant assemblage by another through time.

SUCCESSION, PRIMARY - Refers to succession which begins on bare, unmodified substrata.

SUCCESSION, SECONDARY - Refers to succession which occurs on formerly vegetated areas (i.e., having an already developed soil) after disturbance or clearing.

SYMBIOSIS - The living together of dissimilar organisms, by definition when the relationship is both mutually beneficial and essential.

SYSTEMS ECOLOGY - That branch of ecology which incorporates the viewpoints and techniques of systems analysis and engineering especially those having to do with the simulation of systems using computers and mathematical models.

SYNERGISM - The nonadditive effect of two or more substances or organisms acting together. Examples include synthesis of lachrymotors from other hydrocarbons in sunlit smog and dependence of termites on intestinal protozoans for digestion of cellulose (wood).

TOLERANCE - An organism's capacity to endure or adapt to (usually temporary) unfavorable environmental factors.

WASTEWATER - Water derived from a municipal or industrial waste treatment plant.